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**PHENOMENOGRAPHIC INSTRUCTIONAL DESIGN:  
Case Studies in Geological Mapping and Materials Science**

by

**Janet McCracken, B.Sc.**

**A thesis submitted for the degree of Doctor of Philosophy**

**Institute of Educational Technology  
The Open University**

**2002**

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## **Abstract**

**This thesis explores the role for phenomenography in instructional design. Phenomenography is an educational research methodology that focuses on discovering the qualitatively different ways people experience learning a particular topic. The intent of the research is to come to understand the cognitive interactions that occur when learners attempt to make sense of difficult material, the kinds of difficulties they encounter, and the strategies they apply. This thesis considers how the analysis of these interactions may form the basis for the design of learning materials.**

**Two case studies are presented that illustrate the utility of phenomenographic studies in the design process. The first considers how learner's conceptions of geological mapping can inform the instructional design of a print-based module on interpreting geological maps. A description of the design process details how specific elements were developed using the data, such as objectives and feedback and design guidelines are generated. The second case presented involves a study of learner's conceptions of phase diagrams in metallurgy. The results are integrated in the design of a computer-based learning module on phase diagrams. Design guidelines generated from this case focus on how the data needs to be communicated within the context of a team development environment.**

**The data derived from phenomenographic studies provide descriptions of difficulties learners experience that are often not known to content experts or lecturers. The two cases presented in this thesis demonstrate the gap between what the learner needs and what experts think they need. Communicating the existence of the gap to experts is discussed and design strategies that help to overcome this gap are presented.**

**Integrating phenomenographic study in the design process complements established instructional design models and teaching practice. A four-stage design model is presented that includes generic guidelines that can be applied to any design context. A constructivist designer may use the guidelines to identify and generate problem-based learning tasks. Classroom teachers may use the guidelines to generate examination questions that encourage the learner to demonstrate their understanding of the key concepts associated with the topic of study. The goal for the work presented here is to improve instructional design practice, and in doing so, improve the experience of learning for students.**

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## **Chapter 1                    Introduction to the Thesis**

Phenomenography is a method for acquiring, analysing and representing the qualitatively different ways in which a representative sample of learners experience a phenomenon. The results provide useful descriptions of difficulties learners' experience that can only be derived from this kind of empirical study. This thesis is about improving teaching and learning by integrating the data from studies of learners based on phenomenography. The main research question is "How can phenomenographic studies of learners' experiences be integrated into instructional design practice?"

### **1.1    The Development of Instructional Design**

In recent years there has been a change in the instructional design literature that was dominated for many years by its behaviourist foundation. Evidence for this change can be found in a recent edited volume by Reigeluth (1999a) that calls for a new paradigm of instructional design theories to draw on broader perspectives than were found in the first volume (Reigeluth, 1983a). In the interval between these volumes there has been a shift from behaviourist views to cognitive and constructivist perspectives of teaching and learning. There is no consensus about how to integrate these perspectives into instructional design theory or practice, and even the more contemporary perspectives are lacking in guidance to designers on how to analyse the needs of learners. This thesis is a contribution towards a better understanding of how we might improve teaching and learning through integrating a new approach to learner analysis in instructional design.

Instructional design theories are based on the idea that there are predictable ways that learners will interact with materials that are presented, and that design is based on what you predict the learner will do in the learning process. These theories focus on general principles of learning, and often represent a logical, conceptual, procedural or theoretical structure of objectives to be learned (i.e. learning hierarchies) based on a content expert's view of a topic. Mainstream instructional design theories (e.g. elaboration theory, component display theory, and nine events of instruction) are empirical only in a limited way that does not account for the perspectives and experiences of the learners for whom a particular design is required.



According to Winograd (1996), software design is a "conversation with materials". The process of designing materials for learning can also be thought of as a conversation, which includes a complex set of dialogues and interactions between a variety of stakeholders and their perceptions of the content area, the learners, the context of the teaching-learning environment, and the learning goals. The thesis will present an account of the design process in order to articulate this conversation that will demonstrate how data from various sources and its interpretation is reified in a completed design. This thesis will explore three related themes that emerge as part of the process of applying a learner-centred analysis. First, the impact of an a designer's perception of the design task that includes learner centred studies is considered. Second, the direct implications for design specifications are illuminated through a reflection on the process taken by the author. Third, the indirect impact of carrying out these studies on the various stakeholders in the process is considered. For example, there is evidence that the one of the lecturers involved in the phase diagrams study (Chapter Seven) made substantive changes in the way she presented concepts within lectures as a result of her participation.

This thesis is an exploration both in the context of discovery and in the context of verification (Säljö, 1999). The discovery aspect concerns uncovering and describing the perceptions of the learner through two case studies with the intent to improve our understanding of how to design for learning. The context of verification is considered in a series of evaluation studies that seek to determine the impact of the design on learning outcomes. However, one cannot prove conclusively that learner centred studies such as described here will result in better learning outcomes. Investigating the impact of media on learning outcomes (Dillon, 1998) and attribute-interaction studies (Cronbach & Snow, 1977), have shown that attempts to isolate factors in the learning environment in order to measure their impact leads to inconclusive results. Factors such as additional time working with particular concepts, changes in the way that tutors and instructors thought about and presented concepts as a result of their participation in the research, motivation on the part of students at critical points in their course work (i.e., revision for exams), and the participation of learners in a novel activity that the studies represent, all influenced the learning outcomes. The difficulty of assessing the impact of particular learning interventions has been considered by Jones et.al. (1996). However, the results of the evaluation studies presented in this thesis demonstrate that students who have difficulty in



understanding key concepts associated with a content area benefit from a phenomenographic approach to design.

For each design practitioner, an important issue will be the feasibility of carrying out such learner-centred studies in the context of a normal teaching environment, i.e., how practical is it to place time and effort on this kind of approach. The question is legitimate, as teaching and professional resources within most educational institutions are limited. However, there are two related aspects to counter this concern. The first is the issue of scalability of the method. If the suggested guidelines in this thesis are followed, over time the efficiency of the designer in applying the method will increase. The second issue is the effectiveness of the method. This points to a complementary question of what are the costs to the institution when learning outcomes are not achieved. In many cases, students proceed from one course or level of education to another without understanding important conceptual material that will help them to achieve more advanced capabilities. Learners may 'drop out' because their misunderstanding of fundamental concepts prevents them from fully appreciating the richness and depth of a subject that will internally motivate them to continue, or from effectively applying the concepts they have learned to realistic problems.

Teaching in higher education has traditionally relied on textual resources for presentation of the majority of content material. With the increasing use of the Internet and multimedia delivery environments, the role for visual representations in learning has also increased. In this thesis, the methodology for illuminating learners' understanding of complex conceptual material will also consider how visual representations are interpreted and misinterpreted by learners in order to draw some potential design implications. The first case presented concerns interpreting geological maps; the second is in interpreting phase diagrams. Both cases involve complex concepts and the added dimension of visual interpretation of graphical representations. One of the main findings from both studies concerns the difficulties that people encounter in understanding visual representations. In the case of geology, the difficulty involves being able to mentally manipulate 2D representations in order to 'see' the 3D interpretation. For phase diagrams, the difficulty involves understanding the underlying concepts that are depicted in the representations. Students in both cases struggled with the dimension of time as applied to complex physical systems. In the case of geology, time is a central factor in the process of geological change, where there is a dynamic interplay between geological events and the impact of factors related to time



on geological structures. In the case of phase diagrams, students actually impose a time variable in their interpretations of a composition-temperature representation, although time is not a factor in the relationship.

The above represents a fairly high-level analysis of the data gathered from student interviews and observations of their work. This kind of analysis is driven not from an expert view of the content structure, but from empirical findings. When these findings are presented to experts in the two case studies, the general response is that they are surprised because they certainly did not 'teach' the content in this way. If one were to follow a traditional expert-based-content-structure approach to design, it is highly unlikely that these kinds of findings would emerge, precisely because the source of the data would be experts. The focus for this thesis then is to consider the voice of the learner as a vital and integral part of instructional design and resonates with the following statement from Ausubel (1968);

*The most important single thing influencing learning is what the learner already knows. Ascertain this and teach him accordingly.*

(Pg. 34)

## **1.2 Overview of the Thesis**

This thesis contains Nine chapters that include 5 empirical studies and descriptions of 2 instructional designs. The 5 studies and 2 instructional designs are described below.

**Study 1: Investigation of geology conceptions.**

This investigation describes students' conceptions of visual representations in the form of geological maps. Twelve students were given a map interpretation task and interviewed about their understanding. This analysis was used to generate instructional design of teaching materials for geological mapping.

**Instructional Design 1: Design of Geological Mapping Materials**

The design of the geological mapping materials draws from the data in Study 1, analytical instructional design methods, and Laurillard's Conversational Framework.

#### **Study 2: Evaluation of Learner's Performance on geology materials**

This evaluation study of the geological learning materials focuses on improvements in students' performance. Twenty-four students participated. This study provides input to understanding how the various design elements supported the learners in improving their understanding of the geological mapping task.

#### **Study 3: Evaluation of learning outcomes from geology materials**

This evaluation study of thirteen students focuses on how the students changed their conceptions of geological mapping as a result of using the learning materials, based on a new analysis of the results of Study 1.

#### **Study 4: Investigation of phase diagrams conceptions**

This investigation describes five students' conceptions of visual representations in the form of phase diagrams. The results of this study are used by a team of developers to generate instructional design of computer-based teaching materials for phase diagrams, followed by formative evaluation.

#### **Design 2: Design of Phase Diagram Computer-Based Module**

This instructional design describes the process for integrating the results of Study 4 within the context of a development team and further tests the evolving design guidelines.

#### **Study 5: Evaluation of learning outcomes from metallurgy materials**

This formative evaluation concerns the learning outcomes from the computer-based module on phase diagrams developed as a result of Study 4. This study focuses on identifying how to improve the software, both technically and pedagogically.

### **1.3 Summary of Chapters**

**Chapter One (Introduction to the Thesis)** outlines the main research question and provides a guide to the structure and contents of the thesis.

**Chapter Two (Contextualising the Research in the Literature)** provides a focused review of literature relevant to the main research question. The literature includes instructional design theories, instructional analysis methods, phenomenography, constructivism, situated learning and conceptual change research.



Chapter Three (Methodology) describes the overall methodology of the thesis, using action research as a framework for organising and contextualising the variety of research activities conducted.

Chapter Four (The Geological Mapping Pilot Study) presents **Study 1**; the investigation of geology conceptions. Background material about geological thinking, and literature related to visual representations are presented. The categories of difficulties and approaches to learning revealed in the analysis of student transcripts and maps are described.

Chapter Five (Generating a Learning Package) provides a detailed account of **Design 1**, the design process for the geological mapping learning materials and demonstrates how and where in the design process the data from **Study 1** is used. A 4-stage design model and associated guidelines are generated and presented. The titles are presented here to help provide pointers to the intent of the thesis. As each empirical study and subsequent designs are carried out, the model will be extended and modified to accommodate new guidelines within the major stages.

#### Stage One: Expert Analysis

This stage involves collecting and analysing a variety of expert-based perspectives about what needs to be taught. This is similar to mainstream instructional design task analysis and content analysis. However, the intent in the interaction with the expert in this case includes the determination of the key concepts that will constitute a learner-centred study in the next stage

#### Stage Two: Learner Analysis

This stage of the model involves collection and analysis of data from the learners. It begins with defining tasks that will help reveal the learner's understanding of the key concepts associated with the intended learning materials. It includes the identification and analysis of approaches to learning, interpretation of visual representations and difficulties associated with discipline-specific terminology.



### **Stage Three: Design and Development**

This stage of the model involves the integration of the expert and learner analysis data in order to design and develop the design elements such as learning objectives, learning activities and feedback, and sequencing. At this point, one can proceed on their own or provide guidance to another designer and allow them to analyze the transcripts further.

### **Stage Four: Evaluation**

The evaluation stage is primarily one of reflection. The designer consider each design element and the overall learning package to determine if the learner is supported in overcoming the difficulties revealed in the interviews in Stage Two.

Chapter Six (Evaluation of Learners' performance on geology materials) presents the results of **Study 2** evaluation of the learning materials designed in Chapter Four, focussing on students' performance improvements. Implications for design guidelines are drawn from the evaluation data and experience.

Chapter Seven (Evaluation of the Learning Materials in the Context of a Geological Outcome Space) presents the results of a new analysis of **Study 1** data, resulting in an outcome space and architecture of variation. This chapter also presents the results of **Study 3**, an evaluation of the geological learning materials that focuses on the movement of students between conceptual categories in the outcome space. Implications for design practice are drawn from the new analysis and evaluation data.

Chapter Eight (Phenomenographic Data in a Team-Based Learning Design) provides an account of **Design 2**, the implementation of a design based on the results of **Study 4** in the context of a team development environment. This chapter explores the additional design activities that a team demands when using phenomenographic data in the design of computer-based materials. This chapter also presents the results of **Study 5**, a formative evaluation of the computer-based learning materials. The completed Guidelines for Design are presented

Chapter Nine (Discussion and Conclusions) is concerned with the implications of the research presented in the thesis for the practice of instructional design. A summary and review of the contributions of the thesis to instructional design and phenomenography is presented and future research is described.

The following table summarises the work presented in Chapters Four to Eight.

Chapter	Research	Focus	Students	Data	Finding
Four	Study 1	Geology conceptions	12	Interviews Mapping task	Three conceptual difficulties
Five	Design 1	Geology materials, using Study 1 findings and instructional design approach			Design guidelines
Six	Study 2	Evaluation of materials from Design 1	24	Pre-post tests Questionnaire	Performance improvement
Seven	Study 3	New analysis of data from study 1		Interviews Mapping task	Outcome space Architecture of variation
		Evaluation of materials from Design 1	13	Pre-post tests Questionnaire	Change in students' conceptions
Eight	Study 4	Phase diagrams conceptions	5	Interviews	Three conceptual difficulties
	Design 2	Prototype computer-based learning module designed by team, using findings from Study 4			Design guidelines
	Study 5	Formative evaluation of materials from Design 2	9	Pre-post interviews	Re-design recommendations

*Table 1. Summary of Studies and Designs*



## Chapter 2                    Contextualising the Research in the Literature

The purpose of this chapter is to situate the research of this thesis within the existing knowledge base as reflected in the discipline research literature. The process for arriving at this point has been an interesting exploration to find and carefully select what has been done before that can inform the research, and at the same time demonstrate how the research can make a unique position and contribution to the field.

The design of instruction is a complex and creative process. There are few sources of guidance for designing instructional materials, particularly if the goal for the instruction is to ensure that students understand the implications of fundamental principles and relationships between complex ideas in a subject area. According to Hannafin (1999a);

*Learning is not a unitary concept; learning systems design cannot be either.*

(Ibid.Pg.103).

Because instructional design (ID) as a professional practice is concerned with prescribing optimal methods, and strategies for organizing and presenting materials for a particular instructional situation, it is a good starting point for our review. (Reigeluth, 1983a) Much of the research in this area is focused on interventions and methods that affect learning outcomes, and not what actually goes on for the learner in the learning process. ID research is mainly concerned with establishing the validity of particular instructional methods, and specifically the effectiveness of technologically based instruction in comparison to traditional methods. In a discussion of the future of instructional technology, Heinich (1991) says that;

*We spend too much time telling practitioners what they **should** be doing and not enough time in finding out what the conditions are that shape their decisions, pursuing the latter would take us out into the field to engage us in more naturalistic inquiry.*

(Ibid.Pg.75)

It is this perspective which drives the work of this thesis; to demonstrate that the conditions that shape designer's decisions should include learners' experiences; and to provide practitioners with a design approach that emphasizes collecting and analyzing empirical data from studies of learners to assist in their decision-making.



This chapter will review the research literature on various design approaches in order to frame the study of how to integrate a qualitative approach to discovering and describing student experience. Emphasis will be placed on Instructional Design (ID) as it is specifically concerned with producing knowledge about diverse methods of instruction, optimal combinations of methods (i.e. whole models), and situations in which each of those instructional models is optimal (Reigeluth, 1983a). The process of content analysis aligned to these methods focuses on interviews with subject matter experts, followed by a determination of generic content structures. Analysis of students in this design approach consists of describing features of groups of students, as well as defining prerequisite skills and knowledge. In contrast, studies of learner conceptions that are characteristic of the conceptual change and phenomenography approach, seek qualitatively distinct ways in which students think about a particular topic or problem. The aim is to analyze how students express their experiences of the topic or phenomenon under investigation and to construct categories that reflect the variation of conceptions for a group of students. There is no attempt to select a particular instructional design theory or model or alternative theoretical approach (such as situated learning) on which to focus an integration effort. The intent is to determine where a qualitative approach to learner analysis based on phenomenography might fit in a number of design approaches, and to revisit this analysis in later chapters where guidelines for design will be developed.

The next two sections will focus on Instructional Design Theories and Models and Instructional Analysis. These will be followed by a discussion of Constructivism and Situated Learning.

## **2.1 Instructional Design Theories and Models**

Instructional design is an applied discipline, where the distinction between theory and model is often blurred. Mainstream theories are prescriptive and so can be seen as models of how to carry out the intent of the theory. As a professional practice, instructional designers apply procedures for establishing the optimal methods and strategies to a given instructional situation. Traditionally, these theories and methods have focused on establishing content types, which are then used as the basis for determining presentation sequencing, assuming domain-independence, and to a certain extent context-independence. For example, initially the process of learning a concept is considered the same for biology as it is for engineering, and the context or conditions under which the concept is learned, whether a student is situated in a classroom setting or using educational software, is assumed to be independent of the



processes the student brings to the learning situation. This assumption allows the instructional designer to pre-determine and plan instruction.

Merrienboer (1997) makes the distinction between analytical and empirical models of instructional design. He defines analytical models as those that are highly prescriptive and procedural, and are based on the idea that instruction can be engineered. In contrast, empirical models focus on the creative or intuitive processes in which a designer engages. Merrienboer emphasizes the descriptive nature of these types of models that provide only broad heuristics or guidelines as reference points to the instructional designer.

This distinction provides a useful context for discussing analytical models of instructional design that are presented in the following sections. However, I propose to refine what he refers to as the empirical end of this spectrum to better fit with considering alternative approaches to analytical models. Merrienboer's definition is aimed at the intuitive experience of the designer as the basis for the model, but does not address the experience of the learner directly. For our purposes, an empirical model of instructional design involves the collection of data to inform the process of design. Based on this criteria, there are no existing models of instructional design that would be termed empirical.

### **Analytical Theories and Methods**

One of the most established analytical instructional design theory was developed by Gagné (1985) who put forward the idea that there are different kinds of learning outcomes requiring different kinds of conditions in order for learning to occur. He classified human learning into five categories: intellectual skills, verbal information, attitudes, motor skills, and cognitive strategies. For each of these categories he described the conditions necessary (both internal and external to the learner) for learning to occur. His original work was founded on basic principles of behavioral learning theory, most importantly contiguity, association, and reinforcement. In later work, Gagné incorporates the notion of information processing as a model for the learning process, and contemporary notions of schemas, mental models, and metacognition.

The idea of the learning hierarchy as presented by Gagné is a common method used by the design practitioner. It involves breaking each skill into its component parts. These parts are arranged in a top-down hierarchy, from the highest level or most complex performance goal,



to the lowest level or simplest performance goal. The sequence for presenting the instruction is bottom-up, or from simple to complex. This model is based on a logical view of prerequisite relationships between components of subject matter. For example, if one is to design materials to teach the law of supply and demand using the Gagné model, one would start with definitions of the component concepts (i.e. supply, demand), and move up the hierarchy to present the relationship between the two concepts, and finally to the application of the principle.

There are several difficulties with applying this kind of approach to design, particularly in conceptually difficult domains. The first is that a logical view of prerequisite relationships that define the content or domain structure may not reflect the learning process. It is in fact a representation of an expert's view of the constituent parts that need to be mastered in a particular sequence. In so doing, one is assuming that learning is hierarchical, incremental and predictable from general principles. The second difficulty is that for complex domains, there simply is not a clear hierarchical arrangement of learning objectives, therefore the model is limited to simple, unitary objectives.

Component Display Theory (CDT) built upon Gagné's central notion of applying various generic types of instructional approaches and strategies for given content and learning outcomes (Merrill, 1983). The central tenet for CDT is a content/performance matrix, which prescribes primary and secondary displays representing collections of transactions for single objectives. This theory contends that the key to establishing instructional sequencing and strategies for single objectives can be derived from determining the type of content structure, the level of performance, and the hoped-for learning outcomes. Merrill (1993) agrees that his theory and continuing work is based on the assumption that the learning process or mechanism is basically the same for all people for any topic, and that there are a limited number of generic instructional strategies which can be applied across content areas. Because CDT is only concerned with single objectives, it can not prescribe design methods for dealing with multiple objectives or more complex materials.

Reigeluth and Curtis (1987) argue that a hierarchical approach such as Gagné's is necessary, but not sufficient for sequencing instruction. Reigeluth's Elaboration Theory prescribes instructional sequencing based on identifying a single content orientation (conceptual, procedural, or principled), epitomizing fundamental and representative ideas, and then



elaborating, and summarizing details associated with these ideas. The designer selects the most important content orientation that relates to the goal of instruction, and sequences content based on this decision. This theory provides a better methodology for integration of content by providing direct support to the designer to develop instructional strategies. However, the basic premise that content can be first classified as having a dominant orientation type is problematic. It is extremely difficult to determine a dominant content orientation for complex domains that necessarily have multiple content orientations. For example, it is reasonably straightforward to determine that teaching learners to classify plant types represents a concept orientation. But how would one classify organic chemistry? It appears then that the task for the practitioner is to follow a process similar to that of creating a learning hierarchy in order to break down the content into discernable components in order to determine content orientation.

However, more recent work (Reigeluth, 1999a) provides a new method titled The Simplifying Conditions Method (SCM) for instantiating the Elaboration Theory. He claims that this method encourages a very different kind of simple to complex sequence from a hierarchical one, one that is more holistic and less fragmented. He incorporates the notion of 'enterprises', which he defines as collections of various types of content orientation as opposed to one content orientation. He contends that by incorporating the notion of enterprises, design will be more holistic. However, the focus is clearly on analyzing content, followed by decision-making on scope and sequencing that is dependent on a detailed analysis of the content.

In summary, most analytical ID theories and methods are appropriate and effective for the design of simple procedural skills but offer little guidance for the analysis of complex cognitive skills or prescribing sequencing or strategies for teaching understanding (Winn 1990; Ryder 1993). Gagné and Merrill (1990), agree that current instructional theory is inadequate for considering the problem of multiple objectives, or integrative instruction, and that indeed most theories and models handle single objectives very well, but are unable to provide guidance for the designer where multiple skills and knowledge are concerned.

Merrienboer (1997) has recently developed a four-component instructional design model (4C/ID-model) for training complex skills that goes some way to address the problem of multiple skills and objectives. This model makes distinctions between recurrent and non-



recurrent skills, and the kinds of instructional strategies that are appropriate for training each type. He defines recurrent skills as those that must be performed as rule-based processes that are possible to be trained to the point of automation. Non-recurrent skills are those that are schema-based, and are performed in different ways over various problem situations. The model suggests a sequencing approach that combines clusters of both recurrent and non-recurrent skills that define a task. In this way, the model avoids some of the difficulties of integrating multiple skills and objectives.

The analytical instructional design theories described above prescribe the sequence of instruction based on logical dependencies in the knowledge domain and on the hierarchy of learning objectives (Bednar, 1991). The emphasis on the practice of design relies on subject matter experts as the source of information for discerning the structure of the domain. This is a necessary part of the design process, since we must articulate an accurate domain model. However, there is a vast difference between the expert model and the process of learning in which the student will engage. This is the crux of the design process; once the domain model is developed, how does one engage with the learner so that they may gain understanding of it?

## **2.2 The Learner in Instructional Design Theories**

In Reigeluth's (1983a) compilation of ten prominent and influential theories and models, there were only two that considered how the learner's initial and continuously evolving knowledge state could be used as an integral part of the decision-making process for sequencing instruction. Scandura's Structural Analysis is based on the idea that "what an individual does and can learn depends directly and inextricably on what he or she already knows" (Scandura, 1983, Pg. 237). This theory is concerned with individual student difficulties, and adaptive strategies to overcome these difficulties. The method for assessing the learner's knowledge takes the form of tests of the learners' knowledge of particular rules in a domain. It assumes an atomistic approach to these objective tests, and as such is limited in assessing higher level conceptual knowledge. Scandura does not address the possibility of clustering groups of rules to indicate conceptual knowledge and so the theory does not provide a learner analysis method that will serve to inform our decisions about designing for learning conceptually difficult material.



Collins and Stevens (1983) presented a 'Cognitive Theory of Inquiry Teaching' which calls for selecting and sequencing content based on the particular misconceptions that a student has at a given time. This is not so much a theory as a collection of techniques for teaching students to construct rules and theories by dealing with specific cases. It is based on extensive investigations of teachers who have effectively applied these techniques, such as selecting counterexamples, and debugging incorrect hypotheses in a variety of contexts. Because the techniques are always applied in a dialogic environment, the teacher has the opportunity to illuminate the kinds of reasoning that learners are using in their problem-solving, and as such this is an interesting approach to carrying out a learner analysis in real-time, i.e. the classroom. However, the inquiry teacher has a specific intent with each dialogue that seems heavy-handed as an approach.

Both these theories are concerned with assessing 'individual' student misconceptions, and strategies for adapting teaching to deal with these misconceptions in real-time. It is the basis for much interesting work in the area of intelligent tutoring systems that have attempted to build adaptive teaching systems that include individual student models. However, the kinds of generative student models required in adaptive teaching systems are extremely difficult, if not impossible, to build. Laurillard (1990) argues that this pursuit is suitable for the cognitive scientist, and that the more interesting pursuit for the educational researcher is to understand and make explicit what the student knows, using this information to generate teaching strategies in adaptive systems, conventional classroom environments, and in the design of instruction.

Reigeluth's (1999a) most recent edited volume calls for a new paradigm of instructional design theories that draw on broader perspectives than the earlier volume published in 1983. This volume is not so much a collection of instructional design theories (although a few fairly sophisticated theories are included) but a representative sample of perspectives on teaching and learning. Two contributions of interest here are from Gardner (1999) and Perkins and Unger (1999), both focus on understanding as an important kind of learning outcome.

Gardner (ibid.) argues that the key to teaching for understanding is the recognition that a concept can only be well understood if a student can demonstrate their competence through multiple representations of the concept. The focus for this work provides us with a glimpse of how we might elevate the performance standards we set for students. However, we are



still left with the difficulty of not only how one determines the level of standards to set, but also how to design strategies that will encourage a learning process that results in understanding.

Perkins and Unger (1999) define understanding as "being able to think and act creatively and competently with what one knows about a topic" and present a four-part framework for designing and delivering instruction for understanding. These are summarized below;

1. Select generative topics (topics that have a rich and expansive character),
2. Develop understanding goals,
3. Engage learners in understanding performances, and
4. Provide ongoing assessment.

The framework goes on to provide a reasonable amount of detail, providing criteria on which the above four points can be reified in practice and provides us with a set of guidelines for design that has the potential for enhancing teaching and learning. However, it is, like Elaboration Theory, content and discipline focused and limited in its analysis of the learning process. In earlier work, Perkins (1992) states his belief that methods of teaching are not the answer to better learning.

*Given reasonably sound methods, the most powerful choice we can make concerns not method but curriculum- not how we teach but what we choose to try to teach.*

(Ibid. Pg.44)

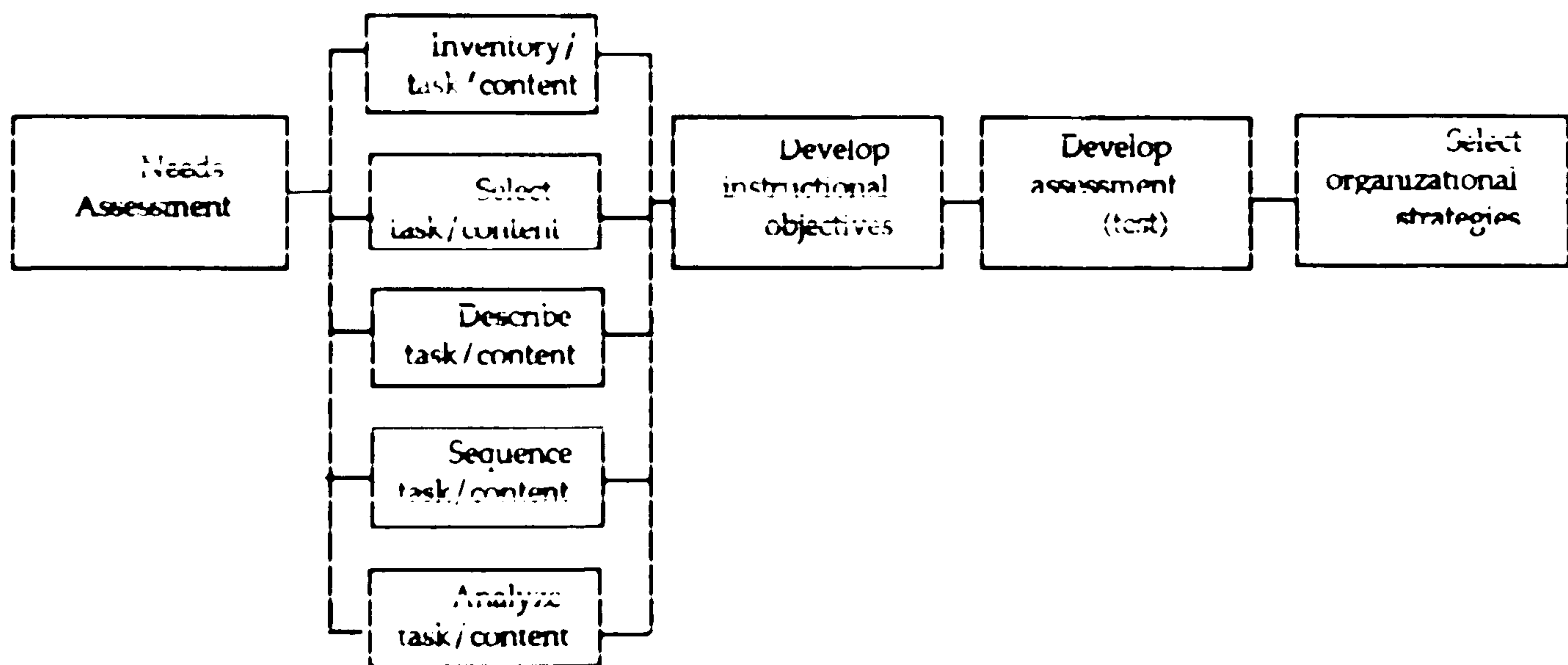
In summary, instructional design theories and perspectives on designing learning environments focus primarily on the content as seen from the perspective of the expert. The analysis of the learner in instructional design theory is insufficiently addressed to be useful in guiding decisions about building learning environments.

The following discussion focuses on a set of activities, which provide a picture of the content and the learner in a given learning situation, a process traditionally referred to as instructional analysis. The result of these activities is the actual blueprint for the course or module under development.

## 2.3 Instructional Analysis

The intent of the previous discussion on instructional design theories was to review some of the resources available to the practitioner in their quest to design effective learning environments. We must acknowledge at this point that design practice and design theories are two different things. This thesis does not set out to develop a new theory of instructional design, but to understand how best to integrate the results of studies of students' conceptions and experiences into the design of learning environments. Having reviewed a number of theories, we now turn to the process of instructional analysis. The analysis process may appear linear, but we are reminded by Visscher-Voerman (1999) in a study of 24 designers and developers that they categorically refute the idea that development is a systematic linear process.

Andrews and Goodson (1980) compared forty instructional design models, and while they varied in detail, there was a general consensus on the major components of the instructional design process. Figure 1 (Jonassen, 1988) is representative of the instructional analysis process and clearly demonstrates the emphasis on content.



*Figure 1. Analysis phase of instructional development process*



*(Adapted from Jonassen, 1988)*

The analysis phase is situated between the identification of needs (i.e. needs assessment) and the development of objectives, assessment and selection of sequencing (organizational) strategies. Needs assessment is often assumed, and there is a reasonably detailed literature that deals with assessing needs. (See Rossett, 1987). However, it is disconcerting to the designer to figure out how to re-interpret the results of a needs assessment that provides some kind of picture of the learner and the learning context into an instructional design model that is only oriented to deal with content issues. There must be a better integration of these processes in order to ensure that vital information that links learner needs to instructional strategies is not disconnected.

In line with the previous discussion of analytical instructional design theories, this analysis process is focused on organizing content in consideration of a particular task or goal that the student is expected to perform and involves determining instructional goals, establishing and representing subject matter as content structures, and describing learner characteristics and their entry-level skills. There are two common ways that learners have been considered in traditional instructional analysis. The first is a consideration of individual characteristics and is reflected in two decades of research on aptitude treatment interaction (ATI). This research, pioneered by Cronbach and Snow (1977), is based on the idea that no one instructional method is expected to be optimal for all students, and that one can study individual aptitudes (intelligence, anxiety, motivation) and determine which instructional method or treatment (varying example types, demonstrations, advance organizers) has the optimal learning effect (Tobias, 1988). However, the findings in these research efforts have been inconsistent, and as such are difficult to integrate in the design process. Essentially, the level of complexity that comes with first determining the match between an individual learner attribute and a method or treatment is an overwhelming data set with which to work for a designer. In addition, the kinds of adaptive learning environments that might be possible based on data from studies of this kind require enormous computational power and understanding of student modeling, two of the main barriers to the implementation of intelligent tutoring systems in the early 1980's.

The second and most common way in which learners are considered in the analysis process involves describing groups of students in terms of general characteristics, such as sex, age, previous courses completed, attitudes, interests, and general learning abilities, and less



commonly, learning preferences. This information is typically collected by interviews with teachers, and/or subject matter experts. At the worst, the designer gains a very shallow view of the typical learner, at the best; an experienced teacher can be extremely insightful about their learners and the kinds of experiences they bring to the learning context.

Prerequisite knowledge that students have of subject matter is of great importance to the designer. In practice, she will attempt to gain some kind of picture of the typical learner by asking questions of the expert about common problems experienced in the performance of a task. This information could be considered second hand, and although useful, one is relying on an expert, who presumably has no conceptual difficulties, to be able to identify misconceptions in his students which he may never have experienced himself or has forgotten. In some cases, a designer will 'observe' the student in performing tasks, however, this mainly occurs in industrial environments in which the kinds of performances are procedural, and little attention is paid to any underlying conceptual difficulties experienced from the learner's perspective. Occasionally a model will suggest that the entry-level behavior of the target group should be analyzed based on empirical data collected by observation of performances (Merrienboer, 1997). However, there is little guidance in this model as to the kind of data to be collected or how the data will be used in design decisions.

The design of learning materials requires that we understand as much as possible about the learners for whom the materials are intended, however, we have seen that analytical instructional design models are focused almost exclusively on analysis of content, and give rather little attention to gathering data about students, much less gathering data directly from students. It is proposed that a more in-depth approach that illuminates more precise information about learners and their experiences is required to better determine where to start instruction, how to subsequently plan for sequencing of instruction, or how to develop effective learning strategies to support the learner. In a recent publication (van der Akker, 1999) describes a research agenda that he calls development research that includes explorative design studies that aim to clarify the design problem in-context and generate tentative design ideas. This idea is closely aligned to the theme of this thesis, and supports the need for better information upon which to base design decisions.

There is no one instructional theory that provides the conclusive answer to the question on how to design the best learning environment. As has been demonstrated in the examples



above, there are a variety of dimensions that underpin these theories including behaviourist-constructivist, descriptive-prescriptive, and analytical-empirical. As discussed earlier, instructional design models can be classified as based on behavioural theories of learning such as Gagné's Nine Events of Instruction, Merrill's Component Display Theory (CDT) and Reigeluth's Elaboration Theory. These theories also can be considered as prescriptive, as they prescribe particular kinds of instructional strategies to be developed in response to particular instructional conditions. And these theories are analytical in that the prescriptions that are suggested are based on a logical analysis of the instructional situation, not on empirical evidence of teaching and learning experiences.

### **Summary**

The work presented in this thesis is concerned with the further development of the analytical-empirical dimension in consideration of developing guidelines that will be useful to the practicing instructional designer. These guidelines are descriptive, as it is not possible to extract prescriptions for every teaching and learning situation if one seriously takes on board the important contribution of empirical evidence. The intent is to come to understand how empirically derived data based on learner experience can be applied in the design of learning materials. By adopting a learner-centred approach, the limiting effects of design approaches that rely on expert perspectives alone may be overcome.

In the next section, contemporary approaches to learning are presented that provide an alternative view to the field of instructional design. The intent of this discussion will be to consider how these approaches incorporate the experience of the learner in the design of instruction.

## **2.4 Constructivism and Situated Learning**

In an attempt to consider alternative theoretical approaches to traditional instructional design as described in the previous sections, there has been considerable attention in both the instructional design and cognitive science literatures concerning the implications of constructivism and situated learning for the practice of design. (Winn, 1990; Jonassen, 1988; Resnick 1989; Bednar, 1991; Hannafin, 1999b). Constructivists argue that knowledge resides in an individual's internal state, and is perhaps unknowable to anyone else. Situated learning emphasizes that knowledge is maintained through interactions with the external, social world. These two approaches are not identical. However, both approaches share the

general philosophical position that knowledge cannot be decomposed or "decontextualized" for purposes of either research or instruction (Anderson, 1996). Resnick (1989) has stated;

*Traditional instructional theory assumes that knowledge and skill can be analyzed into component parts.....we now recognize that skills and knowledge are not independent of the contexts in which they are used.....a new challenge for instruction is to develop ways of organizing learning that will permit skills to be practiced in the environments in which they are used.*

(Ibid.Pg.11)

Earlier we discussed how analytical instructional design focuses on content, and the explicit teaching of concepts, procedures and principles. Constructivism focuses on the development of tasks and task environments that will promote the construction of knowledge, not the explicit teaching of concepts. These are very different perspectives of learning and teaching, and the implications for the designer may appear to be that one must take on board one approach or the other. However, Reigeluth (1997) in responding to the debate between objectivists and constructivists in instructional design has suggested that few theorists or practitioners have the luxury of positioning themselves squarely on one end of a learning systems design continuum; fewer still can be considered justified in their single-minded endorsements or declamations.



## Constructivism

Constructivism is a view of learning that promotes the idea that learning comes about through a process of constructing knowledge. There are two main theoretical areas of constructivism: social constructivism and cognitive constructivism (Marton and Booth, 1997). Social constructivism (similar terms are situated cognition, and situated learning) refers to the idea that knowledge construction is a product of the activity, context, and culture in which it is developed and used (Brown, Collins, Duguid, 1989). Cognitive constructivism or individual constructivism is concerned with the individual's internal construction of knowledge.

Constructivists often argue for replacing direct instruction with self-directed exploration and discovery learning. An extreme view of constructivism might claim that since all individuals construct their own knowledge, it would be rather a waste of time to design at all. A difficulty with such an extreme constructivist approach is that the burden for learning is placed more on the learner than on the designer, which could be seen as a positive opportunity for learners to take more responsibility for their own learning. Or it could be seen as an abdication of responsibility on the part of the designer, who faced with extremely difficult situations, decides to hyperlink and leaves the rest to the learner. It is difficult to imagine how naive learners who may have many conceptual difficulties in an area are to overcome these on their own. In a discussion of pedagogical practice, Marton and Booth (1997) make the point that the extremists of constructivism promote the idea that people must construct their own knowledge by themselves, and in so doing, deny what they call the 'basic principle of pedagogy':

*Whenever you fail to get someone to understand something, you have taken something for granted that you should not have taken for granted. Indeed, there are so many built-in taken-for-granted assumptions in the man-made world-the world of ideas such as science, as well as of the material kind such as instruments, tools, representations- that it is fundamentally impossible for the learner to find out about them on her own.*

(Ibid, Pg.202)

Spiro's Cognitive Flexibility Theory (1992) is a constructivist theory, which is specifically concerned with complex learning requirements. Like Elaboration Theory described in the earlier section on instructional design, this theory involves identifying a number of important



analyses of the content and structuring along multiple sequences. The analogy of paths criss-crossing a landscape is used to describe the learning interaction with the learning materials. At each junction the learner may choose which analysis to follow. Cognitive Flexibility theory prescribes a high degree of learner control over the interaction, and suggests the use of multiple representations of content. The theory is based on the use of both case-based and principled knowledge so that both practice and theory are presented to the student. The conclusion that Spiro comes to is to develop hypertext and hypermedia environments that allow the learner complete control over the sequence and pace of their learning and the opportunity to view cases in different contexts.

In conclusion, whilst there has been some work on developing models for design of learning environments based on a constructivist approach (Hannafin, et al 1999b), the implementation of these environments tends to focus on developing resources that are helpful for students to build their own knowledge. Indeed, Wilson (1995) has warned practitioners of situated instructional design not to expect to capture the content in a goal-task analysis since content on paper is not the expertise one is interested in. He suggests that;

*...the only remedy is to design rich learning experiences where learners can pick up on their own the content missing between the gaps of the (task) analysis.*

(Ibid, Pg. 650)

This strategy is not sufficient for helping students to understand the fundamental principles of a domain in a deep and meaningful way. In fact the most problematic aspect of non-directed learning environments or discovery learning environments is how to help those students who are unable to direct their own learning, and who have very persistent conceptual difficulties.

Driver (1988) has dealt with the issue of constructivist theory into practice in terms of an action research approach to curriculum development for science education, involving both students and teachers. The notion was to take into account the prior conceptions of students in the planning of new curriculum. The most interesting aspect of this approach was the inclusion of the students in the process of not only eliciting the conceptual problems but of clarifying and devising learning strategies (or schemes) to help overcome the problems. Driver's approach was appropriately developed within the context of a dynamic classroom



setting and does not easily translate to a design environment in which the students may not be available throughout the cycle of elicitation, analysis and trials of a variety of strategies that can be accomplished in a conventional classroom setting.

### **Situated Learning**

Cognitive constructivists view the learner as an individual who is engaged in a process of constructing understanding of content material. Situated learning proponents add to this the notion that the process of constructing knowledge is only achieved through collaborative relationships with experts and peers in an authentic social context (Anderson et. al., 1997)

Brown, Collins, & Duguid (1989) argue that for knowledge to be useful it must be situated in a relevant or "authentic" context. They further argue that knowledge is to a great degree, a product of the activity, context, and culture in which it is used. That is, it cannot be taught in the abstract. It must be taught in context. Situated learning proponents, for example, propose that learners can often master complex and difficult material through cognitive apprenticeships, a notion put forward by Brown, Collins, & Duguid (Ibid) where apprentices are inducted into a community of expert practice in which the "teacher" continuously engages in and is a master at the practice being learned. His or her performance constitutes the standard for the apprentice. The roots of the cognitive apprenticeship model lie in the traditional methods by which apprentices acquire skill from experts, and its key features are modeling, coaching, scaffolding, fading and reflection. Cognitive apprenticeship is predicated on the recognition that learning an intellectual task should be supported in the same way that apprentices learn trades: through a process of expert modeling and appropriately scaled, or "scaffolded", support that is gradually withdrawn (or faded out) as the apprentice becomes more experienced. One of the most important considerations for this approach therefore, is the inclusion of "mentoring" and "coaching" support (Carey, 1998).

The key idea in a situated learning perspective is that conceptual knowledge cannot be abstracted from the situations in which it is learned and used. Anderson et al (1997) have listed what they see as the four central claims of a situated learning perspective and have argued each is flawed. Three of these claims and commentary on each one are presented below.

*Action is grounded in the concrete situation in which it occurs.*

(Ibid.p.2)



While skills practiced in schools do not always transfer outside of schools it is also the case that skills practiced in schools, such as reading, do transfer to other contexts. Therefore, although action may be grounded within a context, people do have the ability to transfer skills and knowledge between contexts.

*Training in abstraction is of little use; real learning occurs in authentic situations*

(Ibid, p.4)

There are two powerful words used above that are often used in the situated learning literature; “authentic” and “real learning”. The idea of an authentic task is ill defined, and often translates into teaching students with problems they might use in real-life. However, authentic might also be used as a way of describing abstract problem solving in physics, which is authentic for physicists. The other term, ‘real learning’, is also ill defined. One assumes that it is related to learning that occurs in more authentic environments. I propose that all learning is real to the learner.

*Instruction must be done in complex, social environments.*

(Ibid. Pg.5)

Anderson points out that research demonstrates training is often more effective when nearly independent parts are practiced first, before combining them, giving examples in sports and orchestras, where more time is spent on individual practice than group practice. It is not the case that all learning occurs in a social context. It is however the case that individual learning is likely to be better supported in the context of a social environment.

Anderson’s criticisms point out a potential weakness of a situated learning approach, i.e. that it ignores the needs of learners who need support in understanding complex, abstract concepts, as in much of academic learning. This is in line with Laurillard’s (1993) critique of situated cognition in which she focuses on the essential difference between academic knowledge and everyday knowledge. She argues that not all knowledge is knowable in a direct experiential way;

*Academics want more to be learned than that which is already available from experiencing the world.*

(Ibid, Pg. 27)



A situated learning perspective seems to reject direct teaching of abstract conceptual knowledge, much of which is necessary in order to be a competent person in a complex world, where we must be able to generalize and transfer skills between contexts. This perspective does not provide guidance to a designer of learning materials, particularly where the goal for instruction is somewhat abstract, as in the case of geological mapping.

### **Summary**

Constructivist and situated learning theories view the learner as constructing their own knowledge. Proponents of these ideas often contrast this view with transmission or behavioral theories of learning, where the learner is considered to be a passive recipient. However, these more contemporary views of learning have yet to provide design practitioners with guidance that will help in decision making about structuring content, sequencing, setting objectives or constructing tasks, all of which are necessary to design learning environments. For further discussion, see Driver, 1988.

In the next section, a view of learning and a research methodology called phenomenography is presented that is concerned with gaining critical information about how a student experiences subject matter in the learning process.

## **2.5 Phenomenography**

Ference Marton (1981) introduced the term 'phenomenography' to refer to an educational research methodology that focuses on discovering categories of description of the qualitatively different ways people think about a topic they are learning. The general approach of phenomenography is to use samples of student interview data to construct categories that are expected to have some generality in terms of the student population as a whole (Francis, 1993). The research studies are known as 'phenomenographic' because the results are descriptions of the way in which a group of students conceptualize a particular phenomenon (Laurillard, 1993). These categories of description, also referred to as an 'outcome' space of conceptions', reflect a researcher's analysis of emerging patterns in the way students describe both their approach to a task or problem presented and the reasoning they apply to the problem. According to Marton and Booth (1997) the categories of description represent differences in the experienced structure and meaning of the phenomenon under consideration.



At the foundation of phenomenographic approach is the notion of the first and second order research perspective. A first order research perspective on learning might ask the question “Why do students fail to interpret simple geological maps?” The question assumes that there is some objective criteria on which to base the answer, such as they don’t study long enough, or they don’t have the prerequisite knowledge. A second-order research perspective on learning would be to ask, “What do students think about their failure to interpret a simple geological map”? This question does not assume any kind of objective criteria can be applied to study the question, nor is it possible to answer the second-order question from our existing knowledge. We need to investigate what students think about in relation to their difficulties in interpreting maps. According to Booth (1992) the answers to second-order perspective research is interpretive and descriptive and demonstrates the differentiated nature of peoples’ experience of learning. The kinds of results from these investigations will be of the type that some students think in one way, others think in another way. Phenomenography seeks to reveal the qualitative differences in the way students perceive their experience of learning through the framing of second-order perspective research questions. Marton (1996) says;

*We are not trying to describe things ‘as they are’, but we are trying to characterize how they appear to people.*

(Ibid, Pg. 31)

Phenomenographic studies involve in-depth, semi-structured interviews with students as they attempt to solve a particular problem or perform a particular task. A crucial step in the studies is to provide students with a task or problem to perform which the researcher selects based on how it relates to the research question under investigation. The researcher attempts to provide a task (or group of tasks) which present enough challenge, interest, and richness in a topic area to require the student to produce explanations about their reasoning, and not to rely simply on factual or memorized information to solve the problem.

This approach is one way to gain the learners’ perspective on the process of learning, on how they approach subject matter, on what preconceptions they bring to the learning situation, and on how they perceive and make sense of what is presented to them by an instructor, or instructional materials. According to Beaty (1987);



*The technique (method of phenomenography) is geared to finding out what students understand, rather than how much they understand from the experts point of view.*

(Ibid, Pg. 342)

The kinds of tasks or problems which researchers pose to the student are often very different from the kinds of things students are normally asked to do in the course of their studies, nor would they normally be the focus for assessments for most courses. As can be seen from the following examples, it is unlikely that the kinds of results reported from these studies would be discovered if one had carried out an analysis of content alone. It is because the studies aimed to understand students 'experience that the results are so compelling and provide so rich a source of data that can inform design.

There are three main areas of research within the phenomenographic community. The first is concerned with investigating and describing categories of key concepts associated with a discipline or topic, such as mapping students' understanding of concepts in physics. The second is investigating and describing approaches to learning, and is concerned with the relationship between the way a learner approaches learning and the outcomes of learning. The third focuses on conceptions of learning, i.e., the way in which students describe their experience of learning in general.

There is evidence that conceptions of learning are strongly associated with the way in which students perceive and respond to their learning situation and in doing so is inter-related to conceptions of key concepts and approaches to learning (Säljö, 1988; Marton et.al (1993); Prosser and Trigwell, 1999; Beaty, 1987). Indeed, investigations in this area have shown a positive relationship between deep approaches to learning and learning outcomes (Marton and Säljö, 1984).

This thesis is concerned primarily with investigating key concepts and approaches to learning and does not consider the issue of conceptions of learning. It is hoped that the investigation of learners' conceptions of key concepts and the approaches to learning will provide sufficient scope for informing instructional design decisions, at least at the level of the individual designer.



## Key concept studies

White and Horwitz (1988) studied conceptions of Newtonian mechanics by asking students to determine the validity of various laws using a set of qualitative microworlds. Lybeck and Marton (1988) studied the qualitatively different ways in which secondary school students think about the 'mole' concept in chemistry by asking them to determine the amount of an elemental substance (i.e., mole) contained in a group of plexiglas cylinders, how they arrived at the answer, and how they reasoned about the problem.

While many key concept studies are concerned with physical sciences, Dahlgren and Marton (1977) studied how economics students conceptualize the origin of price by asking them to explain, " Why does a bun cost one (Swedish) crown?" In their analysis of student interview transcripts, they found two main categories of conceptions:

*Conception A: The price is dependent on the relationship between the supply of and demand for buns*

*Conception B: The price is equal to the (true) value of the bun.*

(Dahlgren, 1984, p. 30)

Conception A is consistent with accepted economic theories of price. However, Conception B is not, and reflects a common, everyday notion about how price is established, that is the actual cost of production and distribution. This study is an example of how a simple question can reveal fundamental conceptions which students have about the subject matter they are studying. The analysis, as illustrated above in the economics example, involved identifying qualitatively different common patterns in the way students describe their approach to the task and the reasoning they applied.

Brumby's study (1984) of misconceptions about the concept of natural selection showed that the majority of medical biology students who participated in her studies left school believing a Lamarckian view of evolution based on the notion of need instead of the Darwinian concept of natural selection. She contends that these students demonstrate a faulty pattern of reasoning and tend to rely on a more intuitive theory for explaining the significance of evolution on various medical situations. Her questions to students were a set of unfamiliar qualitative problems that required open-response explanations as well as structured interviews



and the analysis of the results involved constructing categories that best described the nature of the explanation students provided. The students who participated in these studies were very able medical students who were performing well in their studies. The kinds of questions posed to them by this study revealed aspects of their reasoning and conceptual understandings that would not likely have been revealed through standard objective tests.

Neuman (1987) carried out an investigation of children's conceptions related to early numeracy by asking them to describe the strategies they used to solve simple word problems. She carried out a number of studies, and one of the most important findings was that a critical factor in children's later success in understanding rules of arithmetic was the ability to understand the relationships between the numbers 1- 10.

Some of the studies involve asking probing questions as the students' work through a task, others ask the student to retrospectively explain how they worked or reasoned about a task once completed. Retrospective accounts could be more illuminating about learning approaches and strategies as learners have the opportunity to reflect on their experiences before providing their account. However, think aloud protocols can provide very good data on patterns of reasoning. In all cases, careful recording and transcription (either using audio or video) of student and interviewer dialogue is carried out.

Phenomenographic studies can be characterized as two types. The first type is what Booth (1992) refers to as 'pure' or 'basic', where the studies are concerned with descriptions of categories of conceptions for their own sake, not necessarily with a view to determining how one could 'inform' teaching as a result of carrying out the research. The other type of study she refers to as 'applied', and concerns describing student conceptions in order to make some kinds of suggestions about how the results can be applied in a teaching environment. Bowden and Walsh (2000) refer to this type of study as 'developmental phenomenography'. This thesis is consistent with the applied or developmental view of phenomenography.

### **Approaches to learning**

Marton and Säljö (1984) present a study that explored what university students learned from reading an academic text. They discovered two main approaches that students used and termed them "deep" and "surface". They also found that the approach the students employed led to differences in outcome in terms of understanding the text. The deep approach to



learning was characterized as an intention on the student's part to gain understanding of the significance of the author's argument in the text. The surface approach was characterized as an intention on the part of the student to recall isolated facts and concepts presented in the text. These terms are rooted in Gordon Pask's (1976) work on learning styles, and map reasonably well onto his ideas of serialist (surface) and holist (deep) styles of learning.

Table 2 adapted from Ramsden (1988), provides a summary of the deep and surface approaches to learning. This represents an extension of Marton and Säljö's (Ibid) work in order that the categories could be applied to students' work on a range of academic tasks.

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**DEEP APPROACH: Intention to understand**

Focus on 'what is signified'

Relate and distinguish new ideas to previous knowledge

Relate concepts to everyday experience

Relate and distinguish evidence to conclusions and argument

Organise and structure content

*Internal emphasis:* A window through which aspects of reality become visible, and more intelligible

**SURFACE APPROACH: Intention to complete task requirements**

Focus on the 'signs'

Memorize information needed for assessments

Failure to distinguish principles from evidence, new information from old

Focus on discrete elements without integration

Unreflectively associate concepts and facts

Treat task as an external imposition

*External emphasis:* Demands of assessments, knowledge cut off from everyday reality

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*Table 2: Different approaches to learning (adapted from Ramsden, 1988)*

Our understanding of the relationship between the approach to learning and the outcomes of learning are still developing. Ramsden (1988) stated that;

*...different approaches to learning provide part of the solution to the enigma of how qualitative differences in understanding come about.*

Ramsden (Ibid, Pg.20)

This enigma is the result of a complex set of factors in individuals' learning experiences. This thesis will consider how to design strategies that promote a deep approach to learning that will lead to more desirable learning outcomes.



## **Criticisms of phenomenographic research**

Richardson (1999) has criticized the theoretical underpinnings of the field of phenomenography as “ad-hoc and post-hoc”. His main argument is that phenomenography cannot claim to discover conceptions because the data used to derive the categories of conception are only people’s verbal accounts. He says,

*Just as phenomenologists have no basis for characterizing other people’s experiences of the world because they themselves only have access to their own experiences, phenomenographers have no basis for characterizing other people’s conceptions of the world (at least, as causal determinants of how they go about learning) because they themselves only have access to other people’s verbal accounts*

(Ibid.Pg.66)

He believes that this presents an epistemological problem in the mismatch between how people experience the world (a first-order experience of objects and events) and how we gain knowledge of that experience through interviews about second-order knowledge. In order to overcome this problem, he suggests that phenomenographers adopt a constructionist interpretation, by first defining phenomenographic interviews as examples of peoples’ discursive practices and subsequently acknowledging that the categories of description that result from the analysis of verbal protocols are constructions of the researchers, not discoveries of psychological entities residing in the individuals. Phenomenographers do acknowledge that the categories of description are a result of a particular kind of focus and analysis, and do not seek to make discoveries of psychological entities residing in the individuals. Conversely, Marton and Booth (1997) are clearly advocating a non-dualist view of learning.

*The world is not constructed by the learner, nor is it imposed upon her; it is constituted as an internal relation between them. There is only one world, but it is a world that we experience, a world in which we live, a world that is ours.*

(Ibid.Pg. 13)



The above acknowledges that the experience of an individual is constituted as a relationship between what exists in the world and the experience of the individual. It is not a constructed psychological entity of the individual that others have no access to. We all experience the same world and share in those experiences; however similar or different they may appear. This applies to the researcher as well as to the learner, as expressed by Booth and Marton in the following passage;

*One should not, and we have no intention of doing so, consider person and world as being separate. One should not resort to hypothetical mental structures divorced from the world, and we have no intention of doing so. Nor should one resort to the social, cultural world as seen by the researcher only. People live in a world in which they -and not only the researchers- experience.*

(Ibid, Pg.13)

Although Richardson's criticism of phenomenography is based on incorrect assumptions, the field could benefit from researchers' more clearly describing the nature of their studies, and the process by which the interview data was analyzed. There is also a need for more studies that involve observable tasks, which provide observational data and artifacts such as diagrams produced by students in addition to verbal protocols. The inclusion of student work could provide a more accessible entry for others to understand the phenomenographic method, and further our understanding of the role of representations in understanding complex concepts.

### **Reliability**

The reliability of phenomenographic results has been the topic of a number of authors (Marton & Booth, 1997; Bowden, 1995; Francis, 1993; Säljö, 1988). One way of dealing with the issue of reliability is by using independent judges to determine whether the transcripts that were allocated to the categories of description by the researcher are done consistently, and that the wording of the categories sufficiently communicate their meaning to others (Bowden, 1994). This co-judging is a process of testing whether the categories would be supported by the same data by another person, who is normally a researcher who has some expertise in the field of phenomenography. Although it is unreasonable to expect a perfect agreement, reported studies have found agreement between original categories and the excerpts and the co-judging to be between 80 – 90 percent (Säljö, 1988).



Another way to address the issue of reliability is to analyze the results according to a collaborative process (Bowden (2000). He argues that group analysis of transcripts should be part of a phenomenographic method. He says;

*Our procedure has been for the person primarily responsible for the particular analysis to explain their reasons for the categorisations and description, and for the other members of the group to test and probe. This constant 'devil's advocacy', which works both ways when the proponent queries the basis for the objection, provides the discipline that ensures the full evidence of the transcripts is extracted and used to determine the final categories of description.*

(Ibid, Pg.57)

Confidence in the reliability of the results of phenomenographic analysis will never be supported by the kinds of statistical significance data used in traditional psychology studies. Further discussion of this issue will be presented in Chapter 6 where a more comprehensive description of the phenomenographic analysis method results in the development of an outcome space.

### **Summary**

The application of phenomenography may contribute to the improvement of instructional design practice through a focus on learners' experience of key concepts and approaches to learning within a content area. This approach provides one way to fill the gap between an expert view of content that is the main outcome of analytical instructional design approaches and the view of the learner. By taking a second-order research perspective where we ask about the experiences of the learner, we seek empirical results that will inform our designs.

## **2.6 Conceptual Change and Studies of Expertise**

Phenomenography is aligned with conceptual change research, in that the view of learning is one of a change from one way of understanding a concept to a way of understanding as prescribed by a discipline, as well as qualitatively different ways of understanding the same concept (West and Pines, 1985). For many contributors to the conceptual change literature, the focus is to describe the process of conceptual change (or learning) as one of developing and modifying cognitive structures or mental models (Vosniadou, 1994; Chi et.al, 1988).



Vosniadou (2001) explains that science learning is problematic because our everyday, intuitive experience is often fundamentally different to scientific explanations of phenomenon. She further says;

*Learning science requires the radical reorganisation of existing conceptual structures and not just their enrichment, and the creation of new, qualitatively different representation.*

(Ibid, Pg. 384)

Conceptual change research is concerned with the necessary conditions required for change to come about, such as confronting students with their misconceptions. However, Scanlon et.al. (1999) concluded that the role of conflict in conceptual change is not supported, particularly in the context of a collaborative learning situation. She proposes learning through cooperative action, or investigative learning, which is focused on developing collaborative tasks within an investigative framework. Although this thesis has not specifically considered how instructional design may be improved in consideration of the role of collaboration in the learning process, learner-centred studies can certainly accommodate more than one learner, and the data revealed may be very useful in terms of design strategies.

Conceptual change research attempts to describe the process of learning in terms of cognitive processing, often referring to theories of memory, mental modeling and schema theory to try to understand the mechanism by which learners move from one conception to another. This focus is similar to that of researchers who are concerned with the representation and execution of expert performance (Posner, 1988), or studies of expertise. These studies have been described as investigations that;

*illuminate the set of critical differences....between individuals who display more or less ability in particular domains of knowledge or skill. We interpret these differences as primarily reflecting the expert's possession of an organized body of conceptual and procedural knowledge that can be readily accessed and used with superior monitoring and self-regulation skills*

(Chi et al, 1988, Pg. xxi)



White and Frederiksen (1986) designed a set of progressively sophisticated qualitative models of electrical circuits based on extensive protocol studies of children's reasoning about force and motion problems. The design of ThinkerTools used the information about conceptions and misconceptions to build a learning environment that would support the students in developing a desirable evolution of understanding of Newtonian mechanics, and also enabled them to learn about the nature of scientific laws as they transitioned from novice to expert.

Lesgold et.al. (1988) conducted an extensive study of expert and novice radiologists diagnosing x-ray pictures in which he collected observational data and protocols of problem solving. In contrast to earlier studies of radiologists that focussed on visual perception, this study aimed to understand the cognitive processes that influenced how the novice or expert radiologist interpreted x-rays, a particularly complex skill. He concluded that;

*Just as a children's view of the world change character as their experiences increase, so the ways in which radiologists can see human anatomy in radiographs also change, moving from a superficial, probabilistic approach to a deep ability to reason about film content that is supported by highly refined automatic recognition capability.*

(Ibid, Pg. 340)

This kind of study provides detailed data about how novices, in this case quite advanced medical residents, develop expertise, and has a number of implications for ways to improve the way teaching might proceed. For example, Lesgold (ibid) found that expert radiologists were able to appropriate new data (clinical test results) into their diagnostic schema, whereas novices were mainly not influenced by new data in their decisions. This appears to be a potential opportunity therefore to encourage novices to learn how to use new data in the teaching of radiology, or other complex content areas. This might be accomplished through encouraging a deep approach (Ramsden, 1988) to problem solving, where the learner is taught how to look for evidence to support an evolving theory.

From an extensive review of such studies, Chi et al. (1988) provide the following summary:

- Experts excel mainly in their own domain
- Experts perceive large meaningful patterns in their domain



- Experts are fast; they are faster than novices at performing the skills of their domain, and they quickly solve problems with little error
- Experts have superior short-term and long-term memory
- Experts see and represent a problem in their own domain at a deeper (more principled) level than novices; novices tend to represent a problem at a superficial level
- Experts spend a great deal of time analyzing a problem qualitatively
- Experts have strong self-monitoring skills

It is interesting to see this summary in light of the fact that so much of the design community relies on experts to develop curriculum and learning materials for students. Given that their abilities and approaches to solving problems are very different, it is not then surprising then that sometimes the result misses the mark in terms of what is required to help students to learn. However, it provides a useful reference point for helping us to understand how to improve our design by focussing on strategies that will encourage the development of expertise. We must keep in mind that the path between novice and expert is not a straight line, but one that we must come to better understand in order to design more effective learning opportunities.

A conceptual change and phenomenographic view of learning is concerned with "what" and "how" the student thinks about a concept, not "how much" or "how quickly", and with the process the student goes through in acquiring a way of understanding the concept which is accepted within academic disciplines. However, conceptual change research focuses on developing prescriptive solutions to changing student misconceptions through particular teaching strategies such as confronting the learner with their misconceptions. (Bowden, 2000) Phenomenography seeks to *describe* the variation in the way in which people experience the world. Applying a phenomenographic approach to describing the learner perspective in a teaching-learning context includes not only an account of how a topic is understood in terms of differences in conceptions as in conceptual change studies, but of how categories of descriptions are related to one another structurally and referentially in the form of an outcome space. This focus on making explicit the relationships between the conceptions is one that can be distinguished from conceptual change research. A further distinction between conceptual change research and phenomenography is made by Linder (1993) argues that whereas conceptual change is concerned with invoking changes in the



internal representations through re-organization of the representation (mental model), phenomenography makes no assumptions about internal representations.

Studies of expertise are concerned with understanding the cognitive processing that constitutes conceptual understandings, and focus on the differences in problem solving and reasoning between experts and novices. These studies lack an account of the learning process that would explain how the learner moves from novice to expert.

## 2.7 Conclusion

In this chapter a review of five research areas has been presented and each of these areas makes important contributions to our understanding of designing learning materials. From instructional design theories and models, a designer is guided through a set of systematic activities aimed to ensure that design decisions are explicitly made at every step, particularly for analytical models. However, these models rely on an expert view of content, and as such may not provide sufficiently detailed data about learners on which to make design decisions.

In the review of constructivism and situated learning literatures, the discussion focused on the difficulty of developing 'authentic' activities of the kind envisaged by proponents such as Brown et al (1989). However, the emphasis on task construction and task environments for learning focuses the design on teaching and learning activities, where one could apply the in-depth knowledge gained from a phenomenographic study of learners for whom the tasks are created.

Taking account of phenomenography, a designer can gain insight into the conceptual understandings and misunderstandings for a group of students from studying learners directly. This research specialization provides a clearly articulated methodology for gaining the perspective of the learners' experience. The conceptual change literature provides a detailed psychological description of the process involved in changing from one conceptual framework to another (i.e. learning). And expertise studies provide the designer with some way of comparing the novice and expert, from which to draw implications about strategies for design that may encourage the development of expertise; however, the studies are insufficient in articulating the process of learning.

Having reviewed briefly a multidisciplinary source of literature with significance for the design of learning materials, I propose to investigate how a phenomenographic approach to investigating learner's experiences will generate design decisions more closely targeted on students' needs. In order to investigate this idea, the next chapter presents a pilot study carried out following the intent of a phenomenographic approach in the area of geological mapping. This is followed by a detailed description of the design process in Chapter 5 that results in the development of learning materials that integrate the data from the pilot study.

Throughout the remainder of the thesis, the focus will be to demonstrate the utility of phenomenographic data in generating design decisions, ranging from micro-level decisions such as developing feedback, to macro-level issues such as presenting the data to a team of stakeholders.



## **Chapter 3            Methodology**

This thesis presents of a number of research activities in the form of empirical studies, instructional designs and evaluations. Each of these activities was pursued in order to explore how a phenomenographically inspired approach to instructional design could contribute to positive student learning outcomes and improved design practices. This chapter presents action research as the overall methodology for framing the different research studies and perspectives that are represented in the chapters to follow.

The process of coming to understand the data from a collection of research studies is consistent with an action learning and action research approach, where the researcher engages in a spiral of deepening insights. Carr and Kemmis (1986) define action research according to necessary and sufficient conditions as per the following.

*It can be argued that three conditions are individually necessary and jointly sufficient for action research to be said to exist; firstly, a project takes as its subject-matter a social practice, regarding it as a form of strategic action susceptible to improvement; secondly, the project proceeds through a spiral of cycles of planning, acting, observing and reflecting, with each of these activities being systematically and self-critically implemented and interrelated; thirdly, the project involves those responsible for the practice in each of the moments of the activity, widening participation in the project gradually to include others affected by the practice, and maintaining collaborative control of the process.*

(Ibid. Pg. 165)

The process of conducting a long-term research project such as represented in this thesis is consistent with the process described above. Kember (2000) echoes the above in his seven categories of action research;

- Concerned with social practice;
- Aimed towards improvement;

- A cyclical process;
- Pursued by systematic enquiry;
- A reflective process;
- Participative, and
- Determined by the practitioners.

(Ibid, Page 24)

Each of these characteristics is discussed in the following sections in order to frame the thesis research in the context of action research.

#### **Action research is concerned with improvement of a social practice**

Teaching and learning, or more broadly education, is the social practice that is the subject matter of the thesis research. The research sets out to consider how instructional design practice may be improved as a strategy for improving education. The intent is to build a framework that will guide designers and teachers in carrying out data collection and analysis of student conceptions that will lead to more informed design decisions.

#### **Action Research is a cyclical process pursued by systematic enquiry**

In order to build a design framework that can address the needs of designers and teachers, the research in this thesis needs to be carried out which are representative of situations in which these professionals may work. Case studies of authentic teaching and learning situations will provide the authentic instructional design context and the student learning context in which to test the designs. Each of the cases in this thesis constitute a cyclical design within an authentic context, involving the following activities:

- Identifying of learning needs
- Consulting subject-matter experts
- Designing learning materials
- Testing the designs with students
- Collecting data from student learning activities
- Interviewing students and experts
- Observing students
- Administering questionnaires



Within and between the above activities are nested analysis, reflection, and redesign processes which all contribute to an evolving research enterprise. In order to organize the research it is necessary to sequence a series of studies for each of the two cases that allows for the processes and activities to inform one another.

The cycles of planning, acting, observing, and reflecting are all activities that comprise the overall approach to the thesis as well as the activities within each study. The main educational research methodology employed is based on phenomenography, a rigorous and systematic research method using in-depth interviews and intensive data analysis, which seeks to discover and communicate the qualitatively different ways that people experience phenomena. The research was planned so that the results of each study could inform the subsequent research activity. In response to each study, the reflective review process led to the creation of a set of guidelines for instructional design. These design guidelines are initially created as a set of categories and are elaborated and refined as data from each study informs their continuing development.

#### **Action Research is a participative and reflective process**

Research of this kind has to involve learners and subject experts as participants in all stages of the sequence of studies. The subject experts provide guidance in defining the kinds of key concepts to study and how to interpret the student transcripts. The learners provide their experiences through participating in discussions of their understanding of key concepts. The software designers provide their interpretation of the results of the key concept studies through the development of teaching software.

Although Action Research requires active participation by many key people in the process of carrying out the research, the author of this thesis (referred to subsequently as the principal researcher) was responsible for establishing the overall goals of the research, that is, to come to understand the role of phenomenography in the practice of instructional design. In this regard, the research was driven from a single individual who was influenced by the participation of others and who relied on their perceptions to clarify the results. The principal researcher reflected on all of the contributions of the various participants and on the process of the research, finally developing a set of design guidelines that will continue to evolve as further experience is gained, both in the method of phenomenography and in the application of the guidelines to future instructional design efforts.



This approach to action research is congruent with the ideas expressed by Schön (1983) in relation to the development of professional knowledge and reflection in which the individual engages in a cycle of planning-action-reflection in the context of their own practice. This is in contrast to a collaborative inquiry approach to research (Bray et.al. 2000) in which the intent from the outset of the work is to establish a collaborative group of researchers who share in the definition and conduct of a research project. The issue of ethical considerations in relation to research involving the intellectual contribution of participants is further explored in Section 3.3 Roles of Participants and Ethical Considerations.

### **3.1 The Path of the Research**

An action research paradigm provides a framework for articulating the path of the research. This section describes the overall path, focusing on how the guidelines for design were developed, when they were specified and how and when they were revised.

The research in this thesis is concerned with coming to understand how to integrate what can be learned from phenomenographic studies of key concept studies into instructional design practice. An active case study approach was adopted as it provides all of the following opportunities to support this investigation;

- A context that engages with the subject matter and subject matter experts,
- Studies with students engaged in learning the subject matter
- The design and development of learning materials that meet real learning needs and can be assessed with students in an authentic way, and
- Reflection on the design in order to create guidelines for design from the case experience.

Initially, geological mapping was selected and later a second case considering phase diagrams in metallurgy presented itself as an opportunity to extend the research to a new subject area and a new context. Each case is described here.

#### **Geological Mapping: Cycles of Planning, Observing, Action and Reflection**



Geological mapping was the first subject matter to be studied. An initial pilot study (see Chapter 4) focused on learner's conceptions of geological mapping and articulates the kinds of difficulties learners' experience when trying to interpret simple maps. The planning for this study began with reading a thesis by a geology PhD student in the Open University that focused on evaluating a 2<sup>nd</sup> level geology courses and concluded that students' experienced difficulties with visualization of three-dimensional structures. The pilot study was carried out with geology students who were studying geological mapping and the results were reflected on in conjunction with a framework for design outlined in Chapter 5, which then resulted in the action of developing a learning package on geological mapping.

The next research activity was to evaluate the effectiveness of the learning material with the intended students, which is described in Chapter 6. As a result of reflecting on the results of the evaluation, I decided that in order to better understand the nature of the effectiveness of the learning outcomes I needed to fully develop an outcome space for geological mapping. I also decided that I should carry out another evaluation study that would further articulate the nature of how the learning materials influenced the conceptual understanding of the learning materials. After each study, I returned to the guidelines for design and reflected on what I had learned and how what I had learned could be instantiated as a guideline. At the end of the geological mapping studies, the first three stages of the guidelines were complete: Stage One: Expert Analysis, Stage Two: Learner Analysis, and Stage Three: Design and Development.

#### **Phase Diagrams in Metallurgy: Cycles of Planning, Observing, Action and Reflection**

Following completion of the geological mapping studies, I was asked to engage in an evaluation project for a consortium at Imperial College where the team was beginning the design for computer-based learning materials. The planning for the Metallurgy studies began with meeting with an academic and reviewing mid-term exam results to determine if there was a particular topic that students found difficult. We reasoned that we should start the design where the students needed most help. I then designed a small study of students' understanding of the concept of phase diagrams, and the results were shared with the entire management team responsible for the larger TLTP project. This activity resulted in further articulation of the categories of difficulties revealed in the study and consultation with the software designers to determine how they would use the data in their designs. Based on the software designers' interpretation of the results, a computer-based learning package was



developed. In order to assess the learning outcomes for students of the computer-based learning package, an evaluation study was designed by the principal researcher and conducted by others.

The phase diagram case provided an environment for testing the design guidelines that had been developed based on the geological mapping studies. The principal researcher assisted the software designers to instantiate the results of the key concept study on Phase Diagrams into the teaching software. The team dynamic in the Materials Science context provided a new perspective and resulted in expanding the guidelines to include a section on managing and communicating results in a team-based development environment.

### **The Design Guidelines: Cycles of Planning, Observing, Action and Reflection**

As per the previous descriptions of the two cases above, creating and refining the design guidelines was a continuous process throughout the entire research cycle. The first guideline outline was developed following the completion of the first pilot study of geological mapping. This outline appears in Chapter 1 to acquaint the reader with the intent of the thesis. However, the process of creating the outline was one of continuous analysis and reflection on the experience of the learners who participated in the study. As each participant struggled through the difficult task of interpreting maps, I continuously asked myself how the learning materials could be re-designed to help them better understand the concepts they were clearly struggling with. At the same time I considered generic categories of design activities that could become future 'containers' for integrating qualitative data from studies of learners about their understanding of key concepts that would make sense for professional designers.

Once the analysis of the results of the first geological pilot study was completed, and the guideline outline was prepared, I engaged in the design and development of the geological mapping learning materials described in Chapter 5. Throughout this process and throughout the follow-on process of articulating the design and design decisions, the accompanying explanations to the guidelines evolved and new guidelines were added. The design of the materials themselves involved frequent consultation with the geology academics who reviewed and commented on the correctness and value of the exercises that were developed.



The two evaluation studies that followed the development of the learning materials considered both learning outcomes (See Chapter 6) and how students moved between categories of conceptions within the outcome space for geological mapping (See Chapter 7). Based on the results of the first evaluation study, the guidelines were expanded to include an additional phase called Evaluation. I had discovered that the students in the evaluation had tended to focus too much on the discrete aspects of the material and not the overall conceptual aspects. The revised guidelines reflected this discovery and suggested that the designer go back to re-consider how well the learning activities that had been developed supported the student in gaining a high-level conceptual view of the material.

This discovery also led to the decision to explore more fully the outcome space, and to carry out a new evaluation study (Chapter 7) that focused directly on the changes in conceptual understanding. Having conducted the second evaluation study, the guidelines were again revised to expand in the Design and Development phase to focus on drawing feedback to students from the transcript data, the importance of using appropriate graphical representations, and suggestions for interactive environments to support learning. As discussed in the earlier section, the case study on phase diagrams and metallurgy served to focus on how to manage the overall approach to the research and how to articulate and communicate results in a team development context.

### **3.2 The Context of Research**

The research activities, and, specifically, the instructional design practice component, in this thesis were carried out within authentic contexts that were quite uncontrolled from a traditional research perspective. The two case studies presented in the upcoming chapters represent two different contexts. The first set of studies presented in the thesis concerns interpreting geological maps (Chapters 4 to 7). These studies were all focused around a 2<sup>nd</sup> level Open University Geology course. The second set of studies concern the interpretation of phase diagrams in metallurgy and were part of a Teaching and Learning Technology Programme (TLTP) project at Imperial College (Chapter 8).

#### **The Open University Context**

The Open University is a unique institution with a diverse student population and the degree courses are primarily designed for students who study part time through distance



learning. The Open University's admissions policy provides access to university degrees to any adult.

The Open University is well known internationally for creating excellent course material in a variety of formats. In the 2<sup>nd</sup> level geological mapping course that is the focus of the first case, the research focused on the first block course materials that had been developed by an Open University course team as part of a larger course development effort. The students who studied the course did so primarily at a distance, although they were supported by face-to-face tutorials on a regular basis. In addition, the students in the course participated in a residential school in which geological mapping in the field was a major component. The students who participated in the studies averaged over the age of 30 and about half were studying for a science degree while the others were not enrolled for a degree.

The principal researcher worked with the existing course materials and geology academics to determine how to interpret and integrate the results of the pilot study on students' conceptual difficulties in geological mapping. The academics were experienced in the design of stand-alone materials and were able to contribute to the discussion of teaching and learning with technology at a high level. However, they were not experienced in participating in a research activity that focused on conceptual difficulties. In the final chapter, the implications for teachers as a result of their participation in this kind of research are discussed.

### **The Imperial College Context**

The second case study comes from a Teaching and Learning Technology Programme (TLTP) development project that involved a consortium of eight post-secondary institutions in the UK. The primary contact was with academics and students at Imperial College, London. Imperial College is a well-established university that primarily focuses on the sciences. Academic **admittance** standards are high and many of the students have achieved high academic standing in their secondary institutions in the maths and sciences. In contrast to the Open University, students are younger and in full-time residential attendance in classroom settings within the university. All of the students who participated were enrolled for a degree in Materials Science.



The design of the phase diagrams software was a unique initiative within Imperial College, in contrast to the Open University where participation in course teams and stand-alone development materials is a core activity for academics. The principal researcher worked closely with one Materials Science academic who was enthusiastic and interested in teaching and learning with technology. In addition, the software developers hired as part of the TLTP team were special project members and were not regular members of staff of Imperial College. There was collectively little knowledge of designing standalone materials for learning in this group.

The two contexts were very different in which to carry out the studies and the designs of the learning materials. The Open University participants were informative about design and research in teaching and learning and were interested in the outcomes as a way of improving their own practice. One participant at Imperial College was very supportive and interested in how the results of the research could inform her teaching. However, the larger TLTP consortium group was extremely skeptical of the results and utility of the data, and there was no evidence that there might be any impact on the practice of design beyond the one module under consideration in the study.

### **3.3 The Roles of the Participants and Ethical Considerations**

When engaging in any kind of social science research where data and interpretation of data takes place with real people, the issue of ethics must be considered and articulated. The ethical considerations discussed in relation to the students who participated in the research studies are well within traditional experimental approaches in which there are clearly separated roles between the researchers and the subject. In all the studies that took place with students in this thesis, all were volunteers who were informed that all data would be kept confidential through anonymising the data. All student participants were advised and assured of confidentiality by assigning numbers to their data sheets. And all student participants signed a consent form to enable me to use the data anonymously.

The principal researcher in an action research paradigm plays a more participative and collaborative role than in more conventional experimental, survey, and field research that is widely practiced in social science where a strict separation between the researcher and the subject is encouraged. (Bray et.al. 2000). In the research for this thesis, the researcher acted as the phenomenographer, the designer and the evaluator. In some experimental



paradigms, such as controlled condition studies, this multiplicity of roles could be considered as problematic because the role of the researcher may influence the outcome of the research. However, an action learning paradigm encourages multiple roles of the researcher to be defined in terms of the goals of the project.

My role as the principal researcher was varied and complex and included the following;

- defining the research agenda
- designing the studies,
- carrying out the data collection
- leading the analysis of the results,
- initiating and coordinating the resources of the other research participants in carrying out the studies.
- synthesizing the contributions of the content expert participants

There were three other groups of research participants in this thesis; the students who have been previously discussed, and the content experts. The content experts provided collaborative advice and consultation in order to balance and provide evidence for rigor and reliability for the interpretation of the results of the various studies undertaken. The third group is the software designers who created software based on their interpretation of the results of the Materials Science Phase Diagram studies. The following summarizes the nature of their involvement and contributions;

- Suggesting potential research topics
- Reviewing student exams in search of potential research topics
- Reviewing current learning materials in search of potential research topics
- Collaborating on interpretation of conceptual difficulties revealed in the student transcripts
- Reviewing of learning materials designed by the principal researcher
- Co-judging student performance on pre and post-tests included in the learning materials
- Creating software specifications based on interpretation of the conceptual difficulties



The principal investigator explicitly informed all the content expert participants that the research was part of a PhD thesis and their names and contributions are noted in the acknowledgements section of this thesis. In addition, the content experts who served as judges in the interpretation of the pre-and post-tests for the Study 2: Evaluation of Learner's Performance on geology materials are clearly identified and acknowledged in Chapter 5 as Judge 1 or Judge 2. The judges were given six tests that were not identified as either pre or post-test and asked to mark them individually. The principal researcher later put the pre and post-test sets together and asked the judges to consider how well they thought the students had improved from the pre-test to the post-test. This procedure helped to avoid the problem of the interference of the initial interpretation of the pre-test with the matched post-test.

According to a collaborative inquiry approach (Bray, et.al. 2000) members of the collaborative inquiry group as co-participants and co-inquirers for whom the responsibility for the definition and activities associated with the research as shared by all participants. I have not adopted this approach in this thesis, but acknowledge that the participation of the content experts presents a different kind of ethical consideration with regards to the conduct and the acknowledgement of contributions of various participants than occurs in more traditional experimental research paradigms. The locus of control for the conduct of the research always remained with the principal researcher. However, the depth and quality of the interpretations were enhanced by the contribution of the content experts and indeed their participation was a key component in undertaking the research. Throughout the thesis, the contributions of the experts and the students is presented and described.

### **Summary**

This chapter has presented action research as the overall methodology for framing the collection of research studies and activities that will be described and discussed in detail in the remaining chapters. All of the research activities were planned and conducted in order to explore how a phenomenographically inspired approach to instructional design can contribute to improving student learning through improved design practices.

This thesis is about improving teaching and learning by integrating the data from studies of learners based on phenomenography. The remainder of the thesis will focus on the main

research question; “How can phenomenographic studies of learners’ experiences be integrated into instructional design practice?”

The next chapter presents the first in a sequence of studies focusing on the first case geological mapping. The Pilot Study an early attempt to discover what we can learn about applying a phenomenographic study in instructional design. The chapter includes an initial outline for the design guidelines based on the experience of conducting the pilot study research.



## Chapter 4 The Geological Mapping Pilot Study

In chapter 2, a review of relevant theories and approaches to learning and instructional design provided a foundation for bringing together an instructional design problem with a method for illuminating our understanding of the learner's perspective. The purpose of this chapter is to describe an early attempt to discover what we can learn about applying a phenomenographic study in instructional design. This chapter presents a study of students learning to interpret visual representations in the specific case of geological maps. The purpose of the study was to gain insight into the difficulties students' experience and to consider whether this information could be integrated into the instructional design of learning materials in geological mapping. As discussed in Chapter 3, this initial study is the first in a sequence of studies in geological mapping that follow an action research methodology.

As discussed in Chapter 2, phenomenographic studies focus on understanding how people experience a phenomenon by observing what they do, by listening to what they say, and by analyzing what constitutes learning for them. A range of studies in this area have concerned conceptually complex objects of research, such as Newton's third law in physics (Bowden et.al. 1992) the mole concept in chemistry (Lybeck et.al. 1988), recursion in programming (Booth, 1992) and natural selection in biology (Brumby, 1984) These concepts are complex in the sense that it takes hard work on the part of the learner to come to understand their meaning and to apply this understanding in consistent, logical, and persuasive ways. The studies involved in-depth interviews of students working through their understanding and providing their explanations. The researchers spend considerable time in setting the tasks, in carrying out the interviews and in analyzing the results. Such efforts on the part of the student and the researcher are not required for simple memorization or recall tasks but are appropriate for more complex design problems.

I selected the content area of geological mapping because it provided a conceptually complex object of research. An evaluation study of a second-level Open University course carried out by Edwards (1986) described a recurrent difficulty students reported in visualization of interpreting the three dimensional aspect of geological maps. Hence, I began an instructional design study that would explore how the difficulties that persisted for students could come to be better understood in order to inform the design of teaching materials. The methodology employed in the study is inspired by phenomenography, and



focuses on gaining insight into the learner's perspective on the process of learning, on how they approach subject matter, on what preconceptions they bring to the learning situation, and on how they perceive and make sense of what is presented to them by an instructor, or instructional materials.

This chapter begins with a brief review of literature on visual representations and learning, followed by a more focused section on geological mapping and visualization. This is followed by the description of the empirical study, the results, and the conclusions.

## 4.1 Visual Representations

In this section, literature relevant to understanding the use of representations in problem solving and learning will be reviewed in order to better understand the map interpretation task and the difficulties students experience with interpreting complex representations. In a recent special edition on learning with graphical representations, Dobson (1999) warns that;

*... to understand the benefit of diagrams in instructional settings is no more simple than making sense of the languages used to describe the diagrams*

(Ibid.Pg. 303)

Indeed there seems to be no agreed-upon set of guidelines for building representations for use in teaching. Larkin and Simon (1995) define a diagrammatic representation as a data structure in which information is indexed by two-dimensional location. They provide a detailed discussion of why a diagram can be superior to a verbal description and conclude the following;

*Diagrams can group together all information that is used together, thus avoiding large amounts of search for the elements needed to make a problem-solving inference.*

*Diagrams typically use location to group information about a single element, avoiding the need to match symbolic labels*

*Diagrams automatically support a large number of perceptual inferences, which are extremely easy for humans.*

(Ibid, Pg.107)



Although the above is theoretically true, a diagram must be constructed to take advantage of these features and the authors speculate that failing to do so could be a reason that some diagrams do not seem to help problem-solvers. Larkin and Simon (1995) further conclude that the main advantage of diagrams is that the indexing of information is better, allowing more useful and efficient computational processes. However, they may only be useful to those who know how to construct and use diagrams, and so the analysis is limited in helping us to understand the role of representations in learning. According to Cox (1999) a diagram is not always worth ten thousand words- its worth depends upon what kind of diagram it is, which words it represents, who produced and/or uses it and the nature of the task.

In her review of the psychological, education and human factors literatures related to the use of graphics in education, Friedman (1993) concludes that the effective use of graphics requires both good models of the content areas to be learned and good models of the learners who will use them. She refutes the assumptions of the utility of graphical representations for improving learning that underpins most of the literature such as that proposed by Simon and Larkin, above. She argues that more research is needed that focuses on the kinds of information one includes in a graphical representation and the arrangements of that information in ways that are meaningful for the learner. The study of learners then in pursuit of learning to interpret visual representations (i.e. maps) could therefore go some way in helping to analyze how a particular representational system is understood.

Cox (ibid) summarizes a study done by Fransden and Holder in the late 1960's where they used a psychometric test of spatial relations that classified their subjects into high and low spatial visualization subjects. They then taught them diagrammatic techniques such as the use of Venn diagrams and time lines, followed by asking them to solve verbal problems, using the new techniques. Only the low spatial visualization subjects benefited from the instructional intervention and this implies a need for a bridging program to encourage them to make use of graphical reasoning techniques before participating in teaching methods that exploit them. Although this might be a valid conclusion for this particular study, it is worth looking a bit more closely at the representations themselves to see if we might do a better job of building them for use in teaching that helps students.



Lowe (1983) investigated the mental representation developed from a weather map by professional and non-meteorologists. He found that meteorologists were able to construct semantically based mental representations because they possessed extensive domain-specific meteorological knowledge. Non-meteorologists, however, constructed more superficial mental representations, based upon domain-general, visuo-spatial characteristics of the weather map. He concludes therefore that the use of diagrams in instruction may fail to bring the desired learning benefits, and that students may in fact be at a disadvantage when certain kinds of diagrams are used. He suggests that

*..... teachers may need to discriminate between different types of diagrams and see abstract diagrams as a potential learning problem in themselves rather than as a solution to those problems.*

(Ibid.Pg. 177)

As educators and designers we must take the responsibility to teach people about ways of thinking with diagrams and graphics. Cox (1999) suggests that learners should construct their own external representations, and suggests that a number of important effects result, such as subjects examining their own ideas, re-ordering information, translating information from one modality to another (re-representing) and keeping track of their progress through the problem. This certainly seems the way forward for the long-term, but surely we must be able to come up with representations that do not rely on the students to learn a new way of thinking. Scanlon (1997) makes the point that scientific visualization tools, such as 3D rotating molecules developed and used by scientists, should be used by 'science learners' in order to help them join the scientific community. But as we have seen, learners may need support in interpreting and learning from visual representations. Can graphical representations for learning somehow become the bridge to new knowledge, instead of a burden, relying on students' pre-knowledge? These questions are clearly outside the scope of this thesis. However, an examination of the implications for the particular representations (geological maps) used in this study will be explored in an effort to understand possible ways to improve the way mapping is taught.

### **Summary**

The issue of representation is particularly important in considering design of learning materials that are intended for visually oriented disciplines. The literature does not resolve the issue of how visual representations can enhance conceptual understanding, but point to the need for more empirical research. The current study will investigate the kinds of



difficulties visual representations present to learners, and will in later chapters consider design implications that these difficulties present.

## 4.2 Geological Mapping and Visualization

Geological maps represent a plan view of the distribution of rocks seen at earth's surface and can be used to interpret sub-surface geological structures. The study of geological maps requires the ability to "infer the meanings of patterns found in rocks " (Chadwick, 1978) and "the ability to relate two-dimensional surface-rock exposures to three-dimensional sub-surface configurations" (Bezzi, 1991). It also involves the ability to visualize three-dimensional structures that have changed with respect to the dimension of time.

The ability to think in three dimensions has also been investigated in the sub-field of cognitive science referred to as 'spatial abilities,' and is defined by Lisle (1988) as "the ability to mentally manipulate, rotate, twist or invert a pictorially presented object." However, visualization is a broader and more creative skill than simply manipulating objects and can be thought of as the process of creating and manipulating images of concepts and physical structures in association with solving a problem or making decisions. For example, scientists create mental images or models of systems they are attempting to analyze, such as the chemist who speculates on the structure of chemical compounds or the architect who visualizes the design of a building. The ability to classify images, to identify features and to describe abnormalities is a necessary part of training in many professions, such as radiology, anatomy, botany and geology (Sharples, 1991). O'Neil (1992) talks about the ability to "run simulations" of physical systems, which assumes mental processes that can be stopped and inspected at any point in the simulation. This idea is reflected in Chadwick's (1978) view of geological thinking as "the skill of thinking in three-dimensions for visualizing shapes in the mind's eye, rotating, translating and shearing them, and for imaging complex changes over time in the form of a cinematographic visual image". This kind of thinking is complex, and for many people, extremely difficult. In the specific case of developing cross-sections from geological maps, the student is expected to visualize a three-dimensional vertical aspect (a cross-section view) for a two-dimensional visual representation (a plan view map).

Edwards (1986) carried out an in-depth evaluation of a second level Open University Geology course that pointed to a number of difficulties students have in learning various



areas of geology. She found that students had major difficulties in mapping, in particular, drawing cross-sections, and she attributed the source of these difficulties to the inability to visualize three-dimensional features from two-dimensional representations. One student interviewed stated the following:

*I find it difficult to imagine what's going on underground. I can see the map and dip arrows but I can't relate that to the structures. I suppose I don't think in 3D very well.*

(Ibid. Pg. 155)

Course tutors confirmed that some students experienced great difficulty in being able to see rock formations and structures in three dimensions. In a revision of this course, many changes were carried out with the goal of improving the learning experiences for students, including the course material sequence, use of block diagrams, 3D models, audio-visual sequences of the construction of cross-sections, and closer integration of field work to the text in the course materials. The Open University S236 Geology course is organized into six blocks and *Block 1 Maps* is about geological maps, and is the object of the current study. According to the study guide and synopsis of the course, the study of maps is a "basic tool" for geological activities which provides a basis for the student to become familiar with fundamental geological principles, as well as the ability to visualize the three-dimensional form of rock bodies.

Visual representations are important in both physical and abstract systems. Abstract systems, such as formal logic, have been studied in Dobson (1994a) and Stenning & Oberlander (1992). Visual representations of physical systems form an important part of many academic subject areas, including anatomy, mechanical engineering, materials science, geography, geology, architecture, and many more. In these areas, visual representations are considered integral to the understanding of the subject matter. An architect must learn how to interpret and construct plans and drawings that represent a major vehicle for communication in the discipline. Similarly, geographers and geologists must communicate many of their ideas and theories through visual representations, i.e. maps. In order to gain some understanding of the nature of conceptual difficulties associated with visual representations, this study focuses on one particular application in the field of geology, the interpretation of simple geological maps.

Visualization is considered by a number of authors and educators as a crucial capability for students for understanding the discipline of geology (Bezzi, 1991; Chadwick, 1978; Lisle,



1988, Open University, 1983). These skills are also correlated with higher performance in mathematics, chemistry, and architecture, among other scientific and engineering professions. (Linn & Peterson, 1986).

### **Summary**

Visualization is a key capability for learning about geological structures, and the *inability* to perceive structures in three-dimensions is a major obstacle to understanding the geological history of an area. It is less clear how to design teaching strategies that will help learners acquire these skills. O'Neil (1992) contends that visualization is a domain-independent cognitive strategy and suggests the use of direct manipulation graphical simulations for teaching these skills. The Open University study guide (1983) suggests that this capability be best acquired through the study of maps and through drawing cross-sections. Orion (1993) suggests that visualization skills should be taught generically through the use of 3D (three-dimensional) block diagrams or models.

The study described here was carried out to explore the difficulties which students experience in attempting to learn about the three-dimensional nature of geological structures, particularly with respect to the study of geological maps, in order to explore how one might determine design specifications that will lead to learning improvements. It is the first step in investigating whether phenomenographic study can illuminate the learners' perspective in a way in which a designer finds useful for developing strategies that will address the learners' difficulties.

### **4.3 Study Design**

The study was designed to address a second-order research perspective that asks, "What kinds of difficulties do students experience in interpreting geological maps?" As discussed in Chapter 3, a second-order perspective demands that we investigate the qualitatively different ways that people experience interpreting geological maps, as we are unable to answer the question without empirical findings. The second-order perspective is crucial in understanding the basis for integrating phenomenography in instructional design. We have established that decisions that are based on analytical models of instructional design tend to consider the expert view of content as the only 'correct' way of experiencing the content, and the only correct way of presenting the content. This assumption is prevalent in analytical models, and drives the designer to seek data from experts.



A second-order perspective (or a phenomenographic perspective) requires the designer to seek data from learners as well as from experts. We can only answer the question of what the learners' experience if we investigate that experience, since we must assume we do not know the answer and we have to find out. Thus, the inclusion of phenomenographic studies in instructional design appears to be appropriate for ensuring that we gain the learner's perspective. The intent of the investigations is then to gain understanding of how the different ways of experiencing learning of a particular phenomenon may inform our designs. However, the practice of instructional design (and teaching for that matter) is a pragmatic professional activity, constrained by resources that limit the scope of what such an investigation may be able to reveal. Most phenomenographic studies (Lybeck, 1988; Neuman, 1987; Renström et al., 1990) are carried out with the intent to develop sophisticated and deep understanding of the phenomenon under consideration, where the results in themselves are the outcome of the research effort. In this thesis, the intent is to determine how the results can be integrated in instructional design practice and that means taking on board the constraints of the practice. I have taken a pragmatic stance on the level of analysis of the results and therefore have not applied the kind of strict analysis one finds in traditional phenomenographic study. The experience I have gained as designer that I hope to relay in this thesis is the positive contribution of engaging with the students and their difficulties, engaging with the subject experts and their perceptions of the students difficulties, and in attempting to understand these two perspectives in the design of learning materials.

One of the challenges in describing the results of qualitative studies is to help the reader who is not an expert in the subject matter domain to understand the interpretations of the conceptual difficulties being analysed. It is not within the scope of this chapter to provide a course on geological map reading, however an attempt has been made to provide background information to allow the reader to appreciate that some students are confused in their attempts to interpret the maps. It is hoped that the reader will get a glimpse of the nature of those difficulties.

A crucial part of this study was the participation of a subject matter expert in geology, who is also an experienced tutor of the Open University course. Her guidance and input to the study were invaluable.



### **Participants, Materials and Procedure**

The study was carried out with twelve Open University students enrolled in a second level course in geology, five females and seven males, average age 40 years. Students enrolled in the course in February, and the study was carried out in May and June, 3 and 4 months respectively following the study of the material. All students had completed the Block 1 Maps on which the topic of this study was based 2 months before the study was carried out. Students were interviewed in their homes or place of work and were asked to complete a mapping task. The interviewer prepared a list of pre-and post-task interview questions (See Appendix I). Each session began with questions from the pre-interview questionnaire, which consisted of general information about their age, previous coursework, and their general interest in taking the course. This was an opportunity to establish a rapport with the student. The interviewer explained the purpose of the study was to get a better understanding of difficulties students had in mapping. Students were told that the interviewer was not interested particularly in 'correct' solutions, but how they reasoned about the problem and approaches they took.

### **The Task**

The task for the students was to construct a cross-section given a simple geological map, and to develop a stratigraphic column representing the history of how the structures were formed (a geological event history). This task is an integral part of the S236 course requirement. A geological cross-section is an interpretation of the sub-surface geology deduced from the distribution of rock types mapped at the surface. It is a vertical slice view of the sub-surface between two points on a geological map. The 'top' of the cross section is the topographic profile and shows the irregularities in the land surface and shows how hills and valleys interrupt the continuity of the rock layers.

This is a complex task, requiring the ability to make inferences about sub-surface processes that may be in some cases counter-intuitive to ones' understanding of surface or topographic features. For instance, a hill on the topographic surface of a geological map may represent many different kinds of sub-surface structures, not simply a set of deposits, horizontally deposited one on top of the other. Geological structures corresponding to a topographical feature such as a hill can be the result of fold structures, faulting, weathering, and igneous intrusions.



There are over 20 related concepts involved in carrying out this task and the second level Open University course introduces mapping as the first block in the study of geology. Students at this point have limited understanding of the actual rock types they encounter on a geological survey map because they have little domain-specific knowledge. We will return to the discussion of where in the course the mapping module was placed in the discussion section at the end of this chapter, and again in Chapter 4 where the design of learning activities for overcoming the impact of this problem is further developed.

The maps used in this study were developed specifically as 'problem' maps, and were thus simplified so that the task was to interpret processes, without necessarily knowing much about how the rocks may have formed.

Figure 2 illustrates a simplified view of the relationship between topographic features and geological structures.

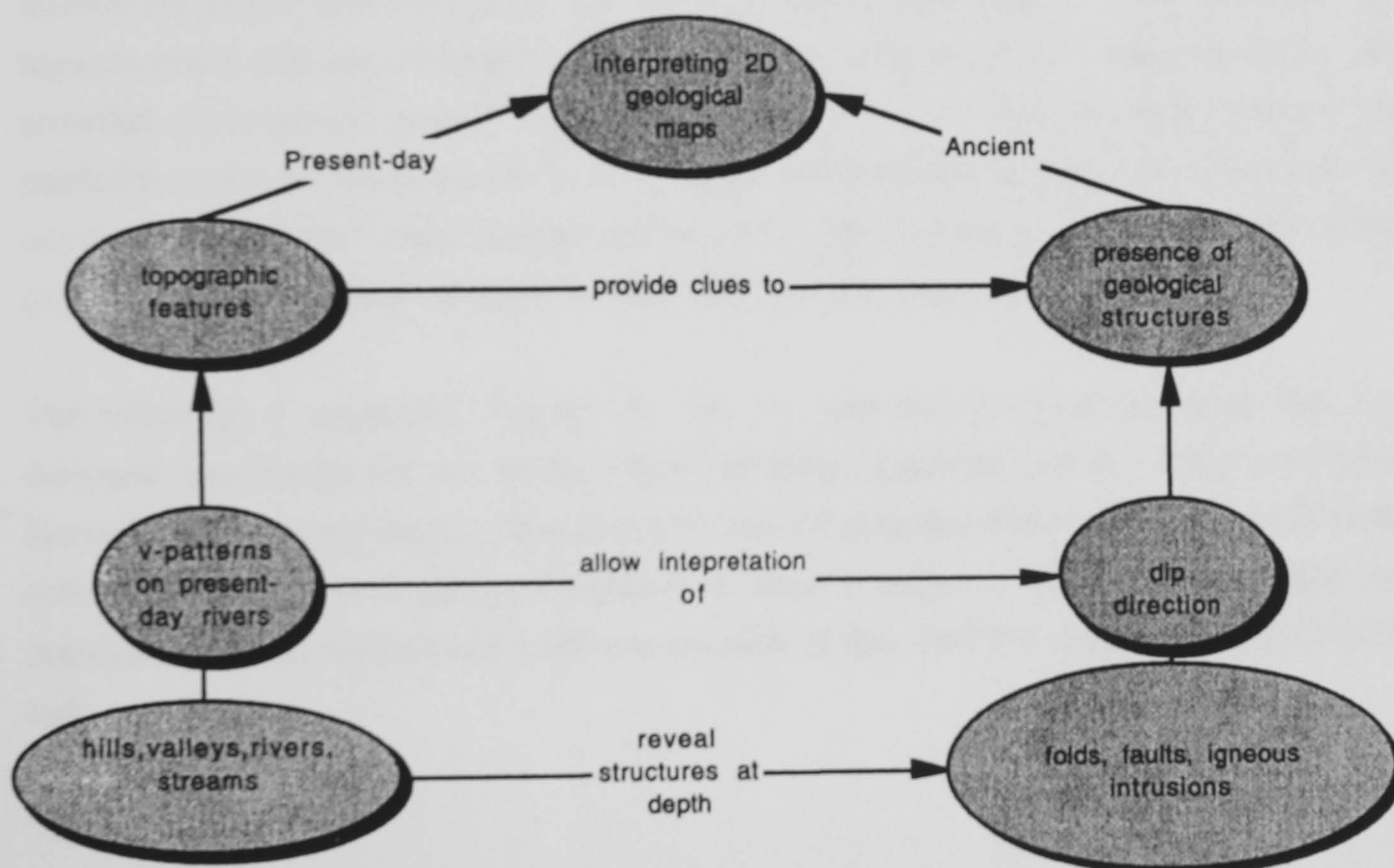


Figure 2. Factors involved in interpreting 2-dimensional geological problem maps



Topographic features, such as rivers, hills, and valleys are present-day structures that are seen easily on a topographic profile of an area. These features interrupt the continuity of the underlying geological structure and provide clues to interpreting what is present at depth. For example, a present-day river will cut into the underlying strata, and if the dip direction of those strata is not horizontal or vertical, a v-pattern will appear on the topography that indicates the direction of the dip of the geological structure at depth.

The students were given a plan view of a geological map that they had not previously encountered in their studies (See Figure 3a) together with its associated topographic profile (See Figure 3b) onto which the cross-section was to be drawn. Students were asked to develop a cross-section view from the plan view of their geological map. Students were instructed to proceed as they normally did with the task and to talk about how they approached it, any confusions that they experienced, and anything they used to guide their solving of the task. After the student completed as much of the task as they could, the interviewer posed questions from the post-interview questionnaire. Each interview was tape-recorded, and session durations were approximately one hour. The interviewer also recorded observational notes. Most students discussed the fact that they realized they needed to revise for the exam based on the kinds of difficulties they encountered in carrying out the task. The interviewer advised students who were having a particularly difficult time to consult with their tutor on specific issues that arose as part of the interview.

The following 4 graphics ( Figures 3a, 3b, 3c, and 3d) are problem maps that were designed specifically for use in the Open University geology course. They were hand-drawn by experienced tutors and scanned for inclusion in this document. The unsolved and solved maps have been grouped together to make it easier to see what the student was presented with for the task and what was possible if they had the expertise to complete the task.

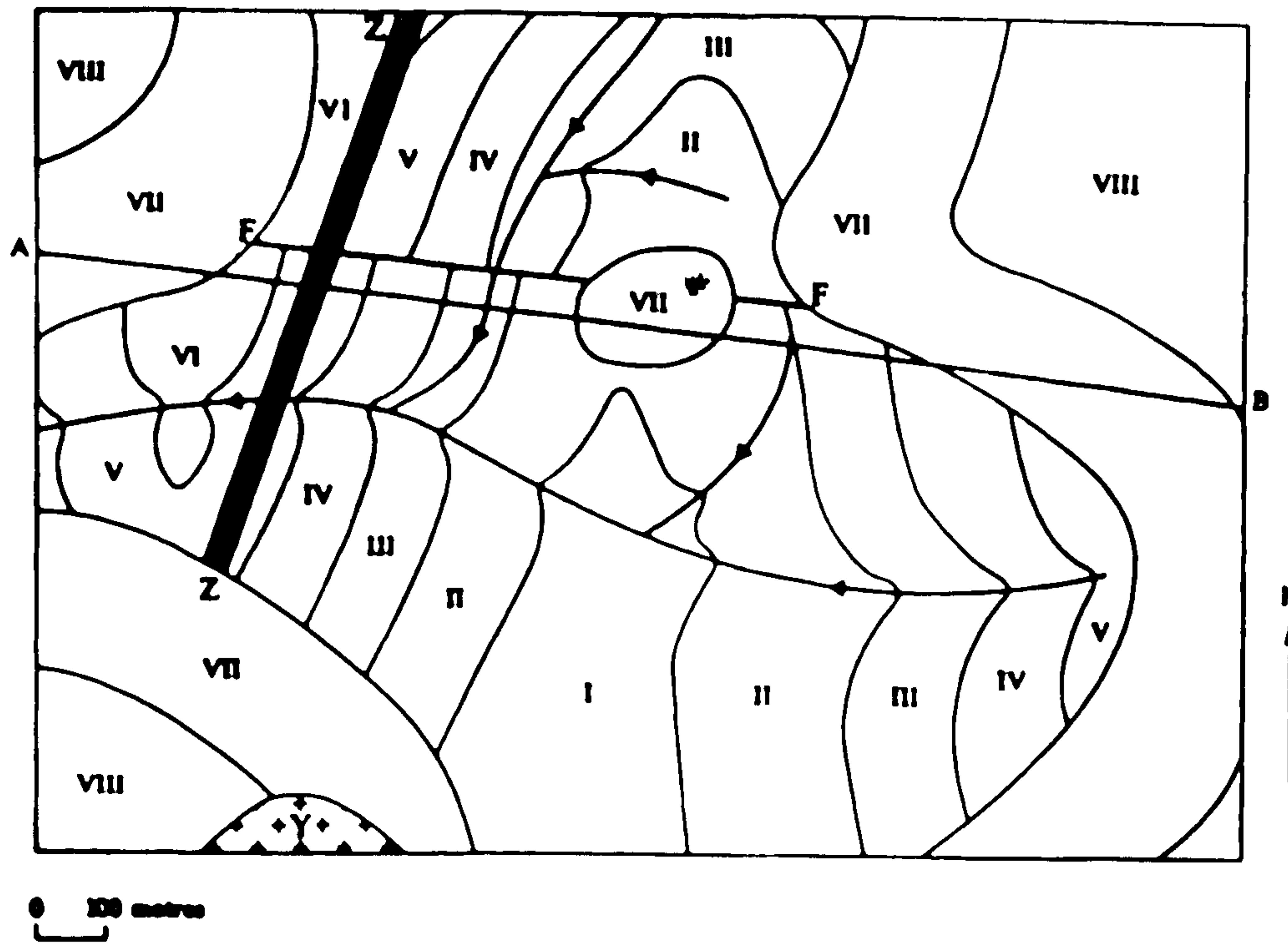


Figure 3a Simplified Geological Problem Map

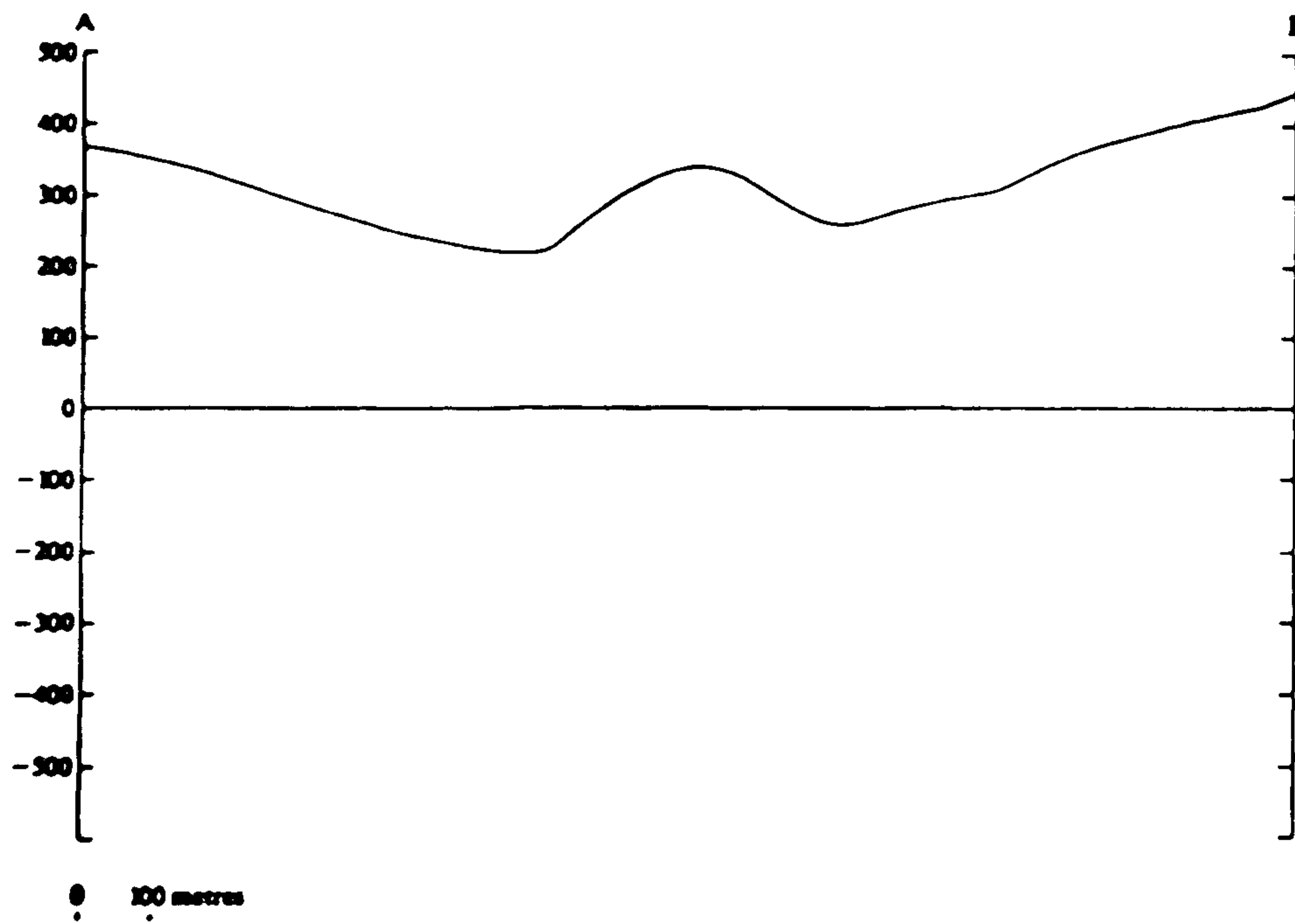


Figure 3b Topographic profile to be used for cross-section of Figure 3a



Figure 3a is a simple problem map developed for the Open University second-level course. The lettered markings (I - VII) indicate rock formations. The F-F line indicates a fault. The Z-Z line is a vertical igneous intrusion, called a dyke. The A-B line is where the student is expected to interpret the cross-section. The \* indicates to the student that this is a special feature to consider. The arrowed lines are indicators of watercourses (streams or rivers) and the direction of their flow, indicating some kind of valley in the east-west direction and the north-south direction.

The following simple definitions may be useful in understanding the understanding the map.

Unconformity: the surface of a stratum that represents a break in the stratigraphic sequence.

Dykes: vertical sheet of magma (igneous rock) pushed up into vertical fractures in rock

Faults: when rock breaks, and the rock on one or both sides of the break moves

Folds: deformation of solid rock due to horizontal compression

Anticline, upthrust folds in which the oldest formations are at the centre of the fold

Syncline: overturned folds where youngest formations are at the centre of the fold

The student was to interpret the sub-surface structures that are directly (vertically) under the A-B line and to draw their interpretation on the topographic profile in Figure 3b corresponding to the A-B line.

Figure 3b is a topographic profile showing the irregularities in the land surface and shows how hills and valleys interrupt the continuity of the rock layers. A model answer to the task is shown in figures 3c and 3d respectively.



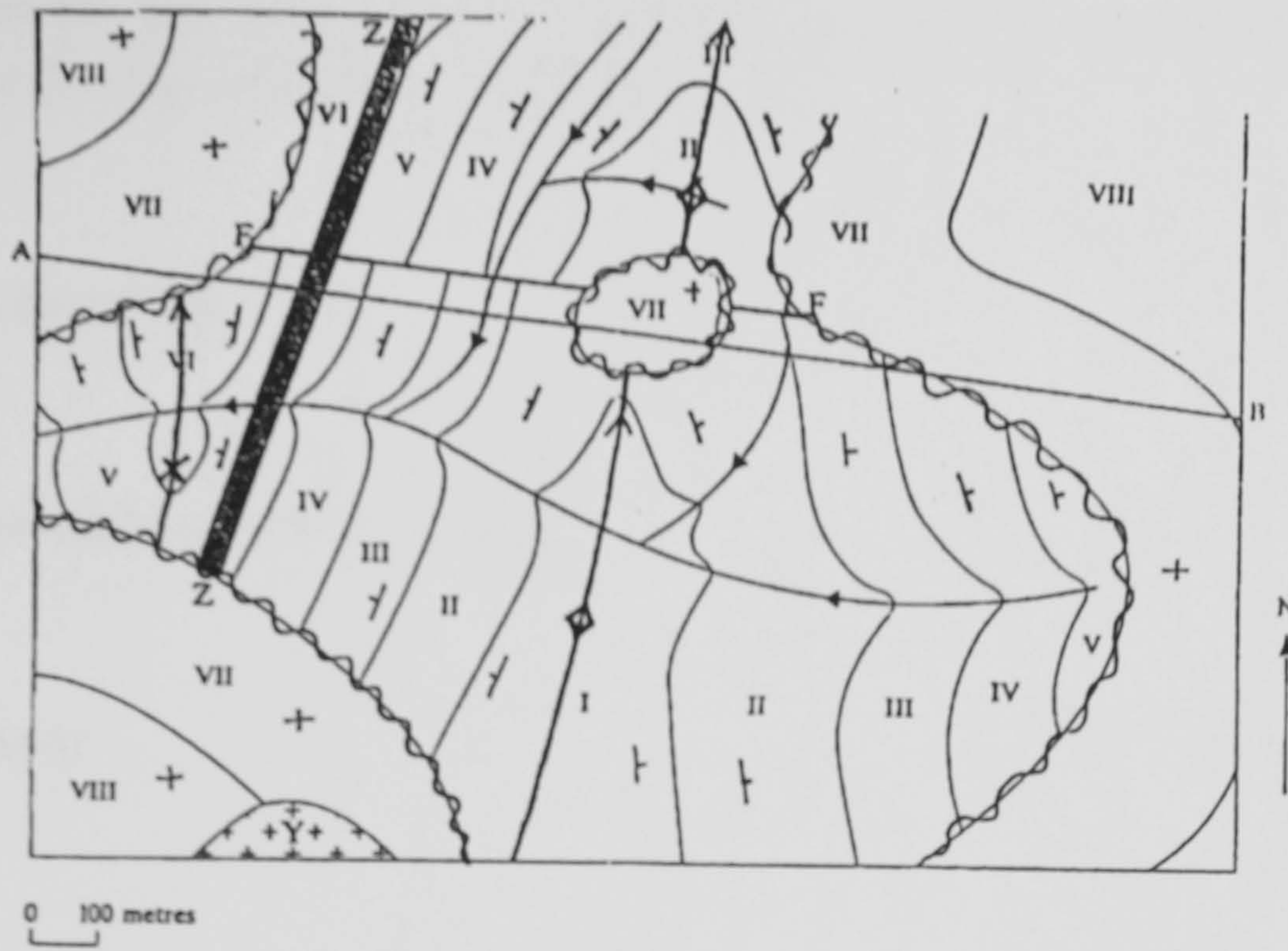


Figure 3c Expert Interpretation of Plan View Figure 3a

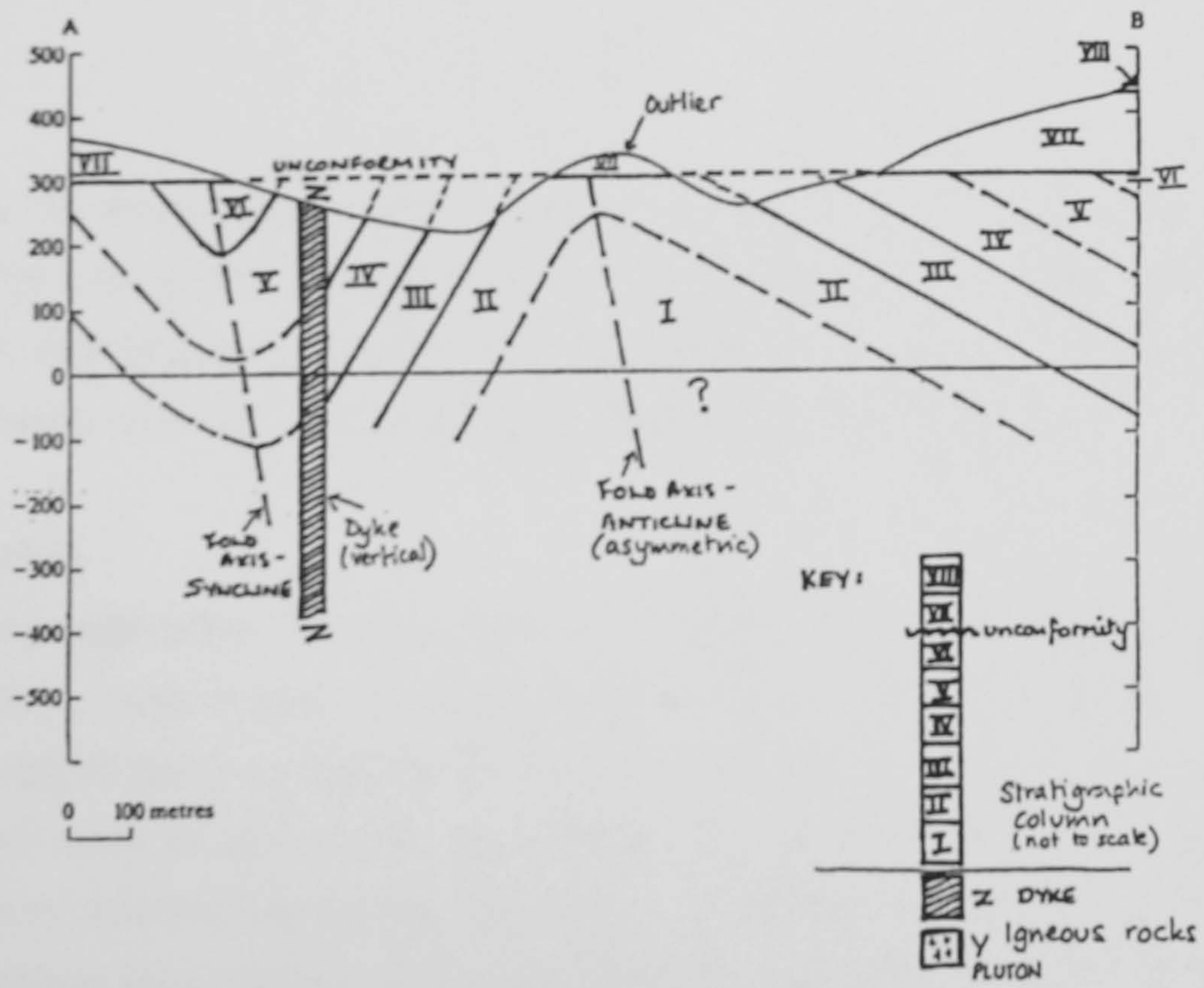


Figure 3d Expert Interpretation of Cross-Section of Figure 3a



Figure 3c provides the expert solution to the interpretation of Figure 3a and shows the marking in the direction of the dip of the rock formations.;






-   
for horizontal formations
-   
for dipping (or non-horizontal ) formations
-   
the unconformity
-   
syncline
-   
anticline

Figure 3d is the interpretation of the cross-section of A-B on Figure 3a that shows the structure of the rock strata as interpreted as a vertical slice directly under the A-B line on the plan view. A stratigraphic column at the lower right-hand part of the figure represents the ages of the strata, with the youngest at the top and the oldest at the bottom.

**Task Solution**

The following explanation is taken from the expert solution provided to students in a handout by the course tutors. In order to get an idea of the complexity of the task for students, I suggest that you read the following whilst looking at first, the problem map 3a (the unsolved map) to see if you can discern any of the markings and interpretations provided. Then, read the explanation again, looking at both the expert map solution (Figure 3c) and the expert interpretation of the cross-section (Figure 3d). Particular attention should be paid to the last part of the explanation that refers to the stratigraphic column in Figure 3d. This should provide a reasonably good picture of what the students were expected to do, and how difficult the task really is.

*An unconformity is indicated by the \* at the base of bed VII. The younger beds (VII and VIII) cut across the folded older series of beds (I to VI). The feature marked \* is an outlier (VII), an island of younger rocks left detached from the rest. It rests on top of the older folded series, and is completely surrounded by them. This was probably due to erosion by the forerunners of the present-day streams. Strike and dip directions are shown on the map. The younger beds are horizontal.*

*Even though there are no topographic contours shown, you can see that the unconformity and younger beds have an outcrop pattern parallel to where you would expect contours to be, given the drainage patterns. If outcrops are at the same height on each side of the valley, then the strata must be horizontal. The general dip direction of the older beds (I - IV) can be deduced from the v-patterns in the valleys. There is one anticline, as shown by the symbol*



*on the fold axis, where the fold closure plunges north.*

*This anticline is offset by the F-F fault, a transcurrent, tear or wrench fault because the fold axis has been offset. The north side of the fault has moved to the right relative to the south side by about 50 metres. There is one syncline, indicated by the symbol*



*on the fold axis. Its fold closure plunges south. Z is an igneous dyke, and it is discordant because it cuts across the beds. It is vertical because its outcrop is unaffected by the topography. Y is a granite pluton, which has been intruded into beds from depth and has a circular outcrop.*

**This following list refers to the stratigraphic column in Figure 3d that depicts the ordering of the rock formations by age and type (igneous or sedimentary) and the geological events associated with the stratigraphic column.**

*The geological history of the area can be described as a number of steps.*

### **1. Deposition of beds I to VI**



2. *Uplift, folding and tilting to North*
3. *Faulting*
4. *Intrusion of dyke Z (doesn't cut younger beds, so must be older than them)*
5. *Uplift and erosion*
6. *Intrusion of Y (because it cuts younger beds)*
7. *Uplift and erosion to present day surface.*

Even in advance of seeing the results in the next section the reader may already have surmised that students may experience difficulties with such a complex task. The student is expected to understand the marking conventions and the terminology, to visualize the subsurface structure relative to the topographic profile, and to develop a theory of how the geological area was formed. This of course is a problem map and problem solution, and is accompanied by other teaching support, such as tutorials, readings, and other maps. However, as we will see in the results, some students found that they struggled to understand even how to get started with this task.

#### **4.4 Categories of Difficulties**

There were two main sources of data collected in this study. The predominant data was the verbatim audio accounts recorded during the semi-structured interviews. In these interviews, learners were asked to talk about what they were looking for on the maps to help them interpret the map, and probed to provide explanations about decisions they made about particular interpretations. The second source of data was some worked maps, although none of the maps were completed in the session. However, in interpreting the verbal accounts, the maps provided a reference point for what students were talking about.

The results of the study are reported in two sections. The first section is concerned with the conceptual difficulties students experienced in carrying out the task. The second section is concerned with the different approaches to solving the task that students exhibited.

Students experienced three related difficulties. The first is a general lack of ability to visualise the three-dimensional perspective of sub-surfaces. The second is the relationship between present day topography as represented on the topographic profile of an area and

the underlying geology. The third is discriminating between two types of fold structures: anticline and syncline. These difficulties are related because the problems experienced in the inability to visualise three-dimensional structures have a direct impact on how the student distinguishes between present-day topography and underlying structures. The ability to correctly discriminate between anticlines and synclines is directly related to the understanding of the relationship between topography and geology.

### **Visualization of three-dimensional structures**

Difficulty in visualizing the three-dimensional nature of the formations was evident with a number of students. They were aware that they were supposed to think about how the formations looked as if sliced through, but really struggled with the notion. Many students drew their own interpretations of what they thought the formations might look like, especially where there existed streams on the topography. This, they reasoned, would 'cut in' and reveal more of the structures. The following excerpts demonstrate the difficulties students experienced;

S4: This is my big problem. I can put the marks on the topography, but I can't tell what to do next....I could draw pretty pictures, but 3D is difficult. I was really surprised, because I pride myself on being an artist, but this 3D stuff, that was a real shock.

S2: Is this a syncline?

I: Is it hard for you to visualise what is going on?

S2: I just see the lines on the paper.

I: What might give you an idea about the direction (of the fold)?

S5: The stream beds. Ummm.....if the....this Visualization doesn't come to me very easily, if the slope of the valley is with the dip...I'm just trying to remember the rules.

These kinds of difficulties are similar to the finding Edwards (1986) reported in her evaluation, and persist despite the development of 3D models and modifications in course materials intended to alleviate these kinds of problems.



### **Present-day topography and geological sub-surface structures.**

Geographical features of a land surface (hills, valleys) create the form of the earth's surface as result of dynamic interplay of surface processes such as weathering and erosion and internal processes such as deposition, uplift and faulting. This dynamic relationship is dependent on the rock type, and its resistance to weathering and erosion. It is the variation in the resistance to erosion of individual sedimentary strata, which is responsible for the topography.

Folded geological structures are rock strata that are folded as a result of compression by lateral pressure over time. A syncline forms when rock beds are folded down in a trough. An anticline forms when beds are folded in an arch. How the resulting topography 'conforms' with these geological structures are dependent on the rock types, weathering, and erosion. The existence of *present-day* features, such as rivers or streams, do not cause geological sub-structures, but their presence can provide clues to the student who is attempting to interpret a map. A syncline (or folded trough) can co-exist sub-surface to a hill or hills on the topography, and conversely, an anticline can co-exist sub-surface to a valley or valleys on the topography. This may appear paradoxical to a student who may not take into account the effects on formations of different orderings of geological events, such as erosion, sedimentation, or folding. The following transcript excerpts demonstrate the difficulty students experienced. For example;

S4: The whole area is a syncline, my difficulty is this river, it is going down then climbing up again, we are talking about a river going upstream. Rivers don't do that.

S4: The river is going down, but the rocks aren't.

S4: So now I am beginning to think so we are looking at a valley, so it is a syncline.....the valley is the base of everything.

S6: ....I notice the streams which are useful for the gradients, but I have to be careful there since sometimes I confuse myself with the dip of the rock and the gradients of the ground.

S6: .....It is surprising there is a stream there when it is halfway uphill, you think it would be running down.

I: So you are looking at the way the streams are running across the formations?

S6: That gives you the topographic layout, and that's what I am more familiar with, and I seem to be overtly influenced by it.

S3: It seems as if the river...here is on high point. It looks as if it coincides with a high point on the profile, which is strange, why should a river be in a high point?

As seen from these quotes, students are familiar with topography and make seemingly logical explanations based on that experience, i.e. they tend to interpret the outcrops on the plan view as though they represented contour lines, and they assume that a folded trough (a syncline) in geology is a valley (as in topography). The inability to visualise the three-dimensional sub-structures adds to the confusion between topography and geology, as students rely on their understanding of present-day surface features to interpret sub-surface features.

#### **Discriminating between anticlines and synclines**

An essential part of reading a geological map is the ability to determine whether a fold is an anticline or a syncline. (Lisle, 1988) The third difficulty demonstrated by students in this study was how to make this distinction. In order to make this interpretation the students must understand the concept of dip and interpreting v-patterns of outcrops. Dip is the slope of a non-horizontal geological surface, and the direction of the dip is the direction in which the surface slopes. The direction of dip can be visualized as the direction which water would flow if poured onto a tilted plane. V-pattern forms on a geological map where a valley or stream cuts in to the rock beds, exposing the direction of the dip of the formations. The way the outcrop patterns V depends on the dip of the geological surface relative to the topography. There are a number of rules about v-patterns taken from the Block One materials that the student can use to interpret their significance of v-patterns, such as;

*1. Where dipping strata cross valleys, v-shaped outcrop patterns point in the direction of the dip,*

*2. Younger strata occur in the direction of the dip, and*



*3. Outcrops always V upstream for horizontal beds and usually V in the direction of the dip for gently dipping strata. The only exception is when a bed and a valley dip in the same direction and the stream has a steeper gradient than the bed, then the bed will V upstream.*

However, as the following excerpts demonstrate, these rules had little meaning to the students, as they were unable to either remember or apply them.

S1: ...I know that the strata are sloping a different way than the strata here but can't tell if it is an anticline or syncline. But I know these shapes here tell me (Note: S1 points to the v's on the map) but I don't know the rules. I know if the river is running that way, then the v's run against the flow, and then on the other side of the structure they flow the other way, but I have forgotten the rule.

S2: It's guess work. I'd say it was an anticline. It dips upstream, doesn't it? So wait, it would be a syncline. It is dipping inwards, upstream:

S5: Normally, you see which is youngest (rock formations), which is oldest, and if one were the oldest then we'd have a u-shaped (syncline), or if it were youngest, we'd have an antiform...I hope. I can't begin to decide.

S6: I'm still confusing myself about anticline or syncline.....I hadn't taken into account these streams, which are the greatest help.....I'm not confident on this.

Students are clearly struggling with how to understand the way that one can use the v-patterns to interpret the direction of the dip, something they need to know in order to help determine whether a structure is an anticline or syncline. These rules, then, do not appear to be meaningful as they students have no idea how to interpret or use them in the context of the interpretation task.

The results demonstrate that students are clearly experiencing difficulty in interpreting problem geological maps. The nature of the difficulties indicates that the teaching to this

point has not provided sufficient support for them to be able to carry out these required tasks as part of their coursework.

#### **4.5 Surface and Deep Approaches to the Task**

This study also investigated differences in the ways students approached the task in order to determine if there was a relationship between the approach the learner takes and their successful interpretation of the map. The analysis of these approaches was based on Marton and Saljo's work on different approaches to learning, in which they studied what university students learned from reading an academic text and found qualitative differences in the outcomes of students' reading (Marton and Saljo, 1984). They found two main approaches that students used and termed them "deep" and "surface", and also found that the approach the students employed led to differences in outcome in terms of understanding the text. The deep approach to learning was characterized as an intention on the student's part to gain understanding of the significance of the author's argument in the text. The surface approach was characterized as an intention on the part of the student to recall isolated facts and concepts presented in the text.

These approaches are directly linked to the students' perception of the task demand. It is not suggested that students inherently 'possess' either deep or surface approaches. In fact, Marton (1984) points out that students applied a surface approach because they thought that was the intent of the exercise. There are two important reasons to consider the different approaches students apply to a task. First, we can learn more about how students' understanding of task demands affects their learning. Second, we can analyze the relationship between the approach a student takes and the outcome of their performance on the task. Having this kind of information, we are then in a much better position to consider ways of defining a task that communicates what we really want the students to experience in the process of learning.

##### **Deep Approach**

In the present study, students had a much less abstract kind of task to deal with than to find the argument of a text. However, their understanding of the demands of the task and their approach to the task influenced their understanding of the interpretation of the maps. Students demonstrated two main approaches to interpreting maps. One approach was to first gain an overall or general idea of what the plan view map represented. Students would look for evidence of processes, which would indicate a history of geological events, such



as folding, or faulting, to build a story of what might have happened in the area. Students who employed this approach tended to concentrate on the visible features (such as dyke intrusions, dip directions) as evidence to support the event history they were developing. This approach is similar to the notion of a deep approach, in that students were concerned with constructing a coherent 'story' of the geological area, not merely carrying out a set of mechanical procedures. The following transcript excerpt shows how one student looked for evidence after he had posited a tentative theory.

S5: There is another one (unconformity) from the end of the fault F...let's think about this. Oh, I see, I think....looks as though we have a downthrust or an upthrust in the centre that is roughly y-shaped on the east-west plane....the evidence for it is, working around clockwise where VII meets VII, V down to I meets VII. (Note: the numbers are the labels for the formations) And on this lower quadrant again there is a I to V meet that, make it look, it would be an inlier.....

I: What are you looking for now?

S5: Clues, normally this is the stage where I just look at it and start thinking.

S5: That would explain, cut certainly, oh right, it is definitely a dip because it cuts the fault boundary,.....I think confirms the idea that they (formations 7 and 8) are part of the same ridge, and supports the idea of later sedimentation.

This excerpt shows how the student was considering the relationship between the concepts he was working with; dips, faults, and unconformities. He is clearly trying to create a coherent story as he looks for evidence. This student was able to provide the most detailed evidence to support his interpretation, as would be expected from Marton's theory that approach, in this case a deep approach, is related to learning outcome, which in this case was a successful interpretation with articulate explanations. Of the 12 students who participated in this study, this student was the only one who demonstrated a deep approach to interpreting the map.

### **Surface Approach**

The other approach demonstrated by 11 of the students was to systematically identify each visible feature on the map before attempting to build a history of an area. Students who used this strategy tended to move quickly to drawing a cross-section and marked the individual features first, before attempting to construct a 'story'. These students tended to

think about the task as either a mechanical or geometrical one, not an interpretative one, and were unable to articulate a history of the area, and had great difficulty in constructing a coherent story.

The general surface approach can be further subdivided into two more distinct approaches; the mechanical and the geometric approach. The geometric approach could be considered a surface approach in that students were focused on correctly identifying and labeling individual features. They attempted to locate the features and map markings, but stopped short of interpreting their meaning in terms of constructing a 'story' of the map. The following transcript excerpts demonstrate an example of how three students applied a geometric approach;

S1: There's a river, that's a dyke, then what am I doing next.....I'll mark the zones I suppose.....now the problem is whether it goes over the top, or that way, whether it is an anticline or syncline.

S6: I would look generally to see if there are any features which catch my eye...one is the fault line, the dyke intrusion, I notice the streams.....I can also see an unconformity running around.

The other subset within a surface approach was the mechanical approach which is characterized by students who focused on the mechanical task of transferring points from the map to the topographic profile, applying a technique without understanding the meaning of the exercise. For example;

S2: I just mark off the different layers and then just transfer them down to the bottom (the profile).

I: I am interested in how you are figuring out what is going on. Are you building up some idea of the history or the events?

S2: No, not really. I mean, I couldn't really answer that kind of question. I would have to draw this about 3 or 4 times to understand that.



The differences between the approaches to learning provides a designer with an opportunity to develop strategies that will encourage the approach that is most appropriate to developing a sophisticated understanding of the topic of study under consideration. In the case of geological mapping, the student who applied a deep approach was able to correctly interpret the map, whilst the students who applied a surface approach were unable to do so. Having an understanding that students apply geometric and mechanical approaches that lead to lack of success provides some clues about potential teaching problems, such as not encouraging the use of techniques without requiring explanations. The lack of domain understanding was a major factor in the students' application of a surface approach. This was due to the placement of the mapping topic early in the course, when students had little or no knowledge of geological concepts. This factor will be further discussed in Chapter 4 where consideration of identifying sources of pedagogic errors (disease caused by the cure, or teaching errors) in the design process is explored in more depth.

### Summary

The study of visual representations of physical systems forms an important part of many academic subject areas, including anatomy, mechanical engineering, materials science, geography, geology, architecture, and many more. This study has demonstrated that interpreting a geological map is a complex task, requiring both domain-specific knowledge of geological terminology and mapping conventions along with domain-general skills in visualizing three-dimensional forms from a two-dimensional representation. This study looked at qualitative differences in students' conceptualization of geological maps and their approaches to the task. The main results were;

1. Students confuse the relationship between present-day topography and sub-surface geological structures.
2. Students have difficulty in determining whether a sub-surface structure is an anticline or syncline.
3. Students have difficulty in visualizing three-dimensional sub-structures.
4. The majority of students applied a surface approach to interpreting maps. For the one student who applied a deep approach, his interpretation was the most detailed and was closest to the expert interpretation.



The literature on visual representations and visualization does not provide sufficient guidance to assist a designer in how to go about designing strategies that help to overcome the kind of deficiencies we have found. The current analysis provides some insight into the kinds of problems students experience with the specific map representations used in the geology and in the next chapter on designing the learning materials I will attempt to build a set of strategies that will encourage representational understanding through domain-specific conceptual understanding.

## 4.6 Conclusions

This chapter has described an initial attempt to discover what we can learn about carrying out a phenomenographic study for the purpose of generating an instructional design. The purpose of studying student conceptions is to ensure that the way students think about and approach subject matter informs the design process. As this chapter has shown, students continue to have confusions about some of the concepts presented in the materials. I have not carried out an in-depth analysis of the results, as per the traditional phenomenographic study. However, the content-specific nature of the analysis in this study is sufficiently detailed to provide us with the means to develop a design and meets the objectives for a pragmatic approach to integrating a qualitative method for gaining the learners' perspective.

In the next chapter the detailed design of a teaching package is presented that integrates the findings of the data presented in this chapter. The design will need to address the major findings of this study; (i) encouraging students to apply a deep approach to learning and (ii) generating learning materials that provide an opportunity for students to overcome specific conceptual difficulties. All design enterprises require the setting of objectives. Using the phenomenographic data in setting objectives will establish the focus for the development of the materials and in doing so lead to the development of learning opportunities that address the conceptual difficulties revealed in the current study. Encouraging a deep approach to learning is more likely to be realized in the design of the interaction between the student and the learning materials. This will need to consider what tasks are set, how the feedback is formed, and how the tasks are sequenced. In addition, the development of visual representations will be crucial in supporting the learner as they develop their understanding of a visual task.



In Chapter 8, the results presented here are re-analysed according to a more traditional phenomenographic approach in order that I will gain more experience with the method and analysis processes, and to determine if a more rigorous approach may add value to the design effort.

## Chapter 5 Generating a Learning Package

Chapter 3 introduced the idea that analytical instructional design studies focus on representing a domain of knowledge based on an expert's understanding of a domain, gaining that knowledge through a series of focused interviews with domain experts. This is equivalent to an academic lecturer's teaching design model, where the lecturer uses his or her own subject matter knowledge to determine what needs to be taught. The Open University materials that were used in the geology course, which included the mapping component described in the previous chapter were developed in this way, using a course team approach that relies on individual lecturers to contribute the subject materials for which they had the most knowledge. The study of students' difficulties described in Chapter 4 demonstrates that for some students the materials as designed in this way did not go far enough in helping them to interpret a geological map. Hence a new design approach may be indicated that would complement or extend the expert's approach.

This chapter presents the design process for generating a learning package that synthesizes the results of the pilot study presented in the previous chapter in order to establish how the knowledge about student difficulties can inform design decisions. The process was one of discovery and reflection at two levels. The first level is pragmatic, using the analysis of the phenomenographic study as input to a variety of design decisions. The second level is analytical; reflecting on how the experience of carrying out the interviews and analyzing the results affected the way the designer thought about various design activities, both logical and creative. Both of these levels will be explored.

Winograd (1996), in attempting to describe software design, talked about the activity of design according to a number of dimensions;

- *Design is conscious*
- *Design keeps human concerns at the centre*
- *Design is a conversation with materials*
- *Design is creative*
- *Design has social consequences*



- *Design is a social activity*
- *Design is communication (ibid, Pg. xix-xxv)*

Although designing learning materials involves all of the above, the two that best capture the process described in this chapter are “design keeps human concerns at the centre” and “design is a conversation with materials”. If the process of designing materials for learning is a conversation, it involves a complex set of dialogues and interactions between a variety of stakeholders and their perceptions of the content area, the learners, the context of the teaching-learning environment, and the learning goals. The design process described in this chapter conforms to Winograd’s account of the design activity.

This chapter presents a retrospective account of an instructional design process in order to articulate this conversation through explanations and design artifacts. This will involve demonstrating how data from various sources and its interpretation was realized in a completed teaching package. The design described is predominantly concerned with keeping human concerns at the centre, particularly the concerns of students.

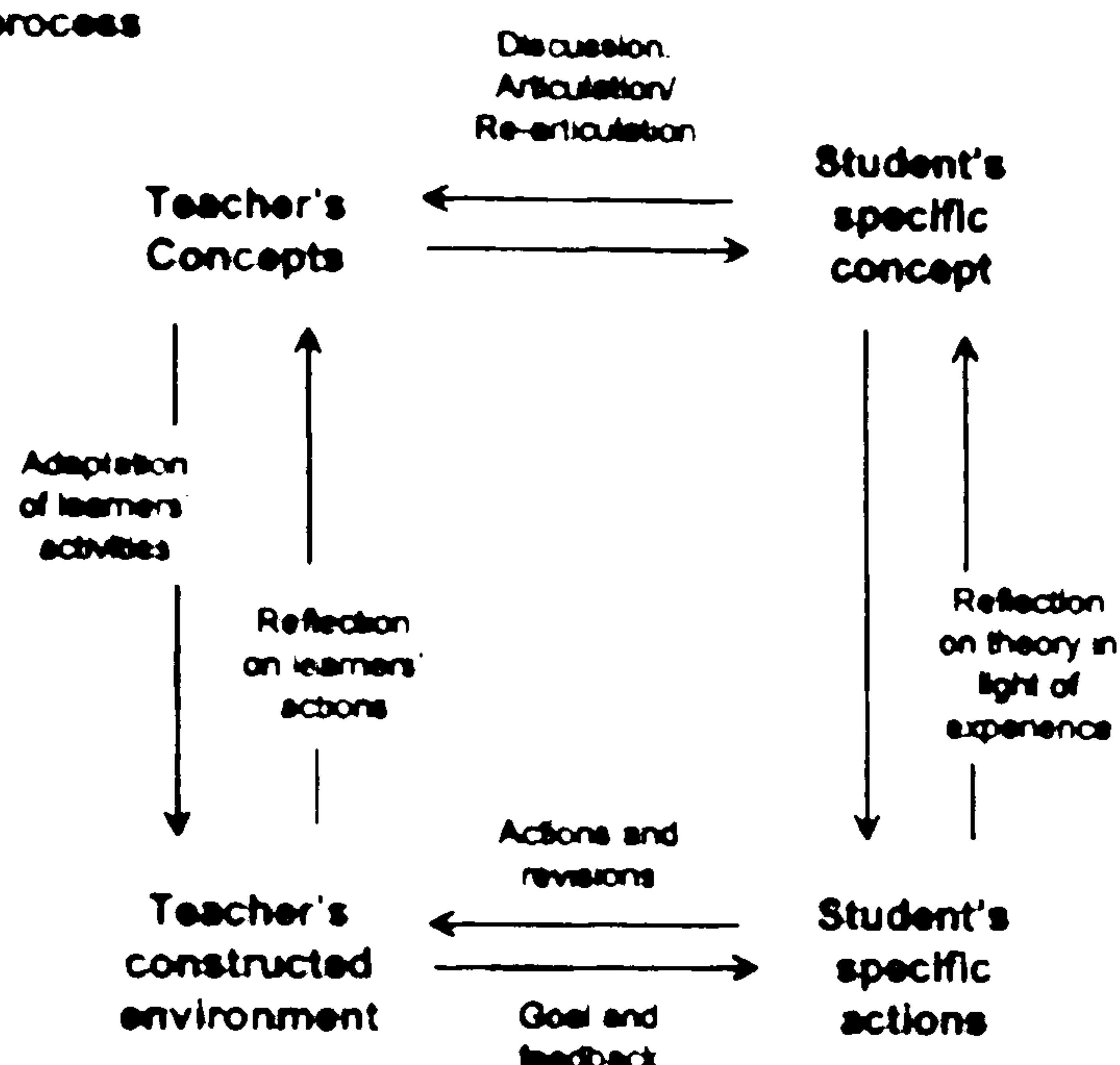
There are four main influences in the design of this teaching package. The first is the conversational model of teaching and learning developed by Laurillard (1993). The second is my experience as an instructional designer, and the theories and models I have applied in a variety of design contexts. The third is the experience of having carried out the phenomenographic study and the fourth, most importantly is the data provided by the experiences of students. Each will be discussed in this chapter.

## **5.1 Conversational Framework**

There are different ways of representing and describing what goes on in the complex process of learning and teaching. Laurillard (1993) provides a comprehensive model of the kinds of necessary communication between a student and teacher for successful teaching and learning. The model is based on the idea that learning and teaching can be thought of as a conversation in which a student and teacher engage in a dialogue aimed at ensuring that each party’s conceptions of the topic to be learned are understood by the other. The model is not dependent on a particular delivery environment, although later in her book, Laurillard (ibid.) describes how various technologies fit into and support this model of learning and teaching.

The model provides a way of thinking about teaching and learning, and implies a way of approaching the design process that focuses on the interaction between the teacher and student. This is a very different focus to that of analytical instructional design models, where the focus is on the articulation of the structure of the content

**Conversational Framework  
for the learning process**



*Figure 4 Conversational Model of Learning and Teaching, from Laurillard (1993)*

There is no implicit or explicit starting point for a teaching-learning interaction with the model. A student might begin an interaction with a question, or a teacher might begin an interaction with an explanation of some concept. We can easily imagine the conversational nature of the learning process in a one-on-one tutorial in which the student and teacher are engaged in discussion of a topic or problem. We can think of the four main anchors of the model as conceptual spaces and environments, as in the following descriptions.

1. **Teacher's concepts;** The teacher articulates their conceptual understanding either through direct explanation or through constructing a task for the student to consider.
2. **Student's specific concept:** The student reflects on the input from the teacher or task, and acts in some way, either through direct articulation back to the teacher in which the student's re-conceptualization of what the teacher has presented is re-presented or through specific actions in terms of a task.



3. **Teacher's constructed environment; the teacher is active in this space, and is responsible for designing the kinds of activities the student undertakes. The teacher evaluates and reflects on the actions of the student, and develops an adaptation of the initial presentation based on that reflection back to the student. This adaptation could be in the form of an alternative representation of a problem, easier or more difficult problems.**
4. **Student's specific actions. These are actions that require some kind of feedback (right or wrong, explanatory) from the teacher or teaching system. These actions could be in any form, from a pattern of interactions with a computer program, to a two-way conversation.**

Laurillard et al (2000) describe a minimalist sequence for learning to take place in a recent article on the use of narrative in multimedia environments, as follows:

1. *teacher presents conceptual knowledge*
2. *student expresses partial understanding via comment, question or answer*
3. *teacher adapts experiential task to help student experience the concept task*
4. *teacher sets goal for student*
4. *student adapts action plan in the light of conceptual knowledge*
5. *student acts to undertake task*
6. *student receives feedback on action*
7. *student reflects on interaction using conceptual knowledge*
8. *student further adapts action plan*
9. *student generates new action to undertake task*
10. *student receives feedback on new action*
11. *student reflects on interaction to develop conceptual knowledge*
12. *teacher reflects on student interaction to begin new dialogue*
13. *student articulates understanding of conceptual knowledge*
14. *teacher gives feedback on student's account*

*This minimalist sequence of iterations of dialogue, action-feedback, adaptation and reflection allows the students to be exposed to new ideas, to link these to enhancing their practice, to improve their practice and link this improved practice to further developed understanding, and to assure the quality of their understanding*

(Ibid, p.4)

This model can provide guidance for different levels of design. At the macro-level, or course level, one can use it to determine which aspects of a course (i.e. texts, computer conferencing, lectures, and multi-media tutorials) support the necessary communication requirements for an entire system. For instance, computer conferencing may provide the

communication mechanism for articulation/re-articulation of conceptions between the teacher and the student. However, the model is probably most useful to guide the design of single topics, or micro-level design tasks, particularly for technology-based learning environments where there is a need to identify in advance how technology can support the learning process. This is not so critical for classroom based environments where there is more flexibility in the way in which teachers and students communicate.

How does this account of the learning process inform our design practice? At the simplest level, our awareness of the needs of learners has been heightened by the articulation of the role for two-way interactions in the learning process. It may seem obvious to anyone who teaches or designs for learning that interaction is necessary. However, this model provides specific guidance for the interactions.

For designers who follow a constructivist view of learning, there is a tendency to place responsibility for learning with the learner (Duffy, 1992). We see in the above sequences that the process is shared and negotiated with responsibility for reflection and planning forming a central role in the learning process for both the learner and the teacher. This model makes it clear that providing resources that learners can access without these other affordances for learning is insufficient.



In order to use the Conversation Framework in design practice, I have attempted to instantiate design elements that arise from the sequence of iterations above. As a starting point, Table 3 represents externally focussed activities, that is, what the two parties involved in the interaction are actually doing that can be observed and transformed into design elements. These design elements could be features of a computer-based learning system or activities within a face-to-face interaction, or even the basis for the design of a computer-conferencing system that supports the activities expressed here.

Student	Generates new task action
	Undertakes a task
	Expresses conceptual understanding (partial) through comments, answers or questions
	Receives feedback
Teacher	Articulates understanding of conceptual knowledge
	Sets task goal
	Presents conceptual knowledge
	Provides feedback

*Table 3 Externally-focused teaching and learning activities*

The table above provides guidance to the development of learning activities and communication functionality that could be developed as part of a design enterprise. A design would need to include facilities to support both student and teacher activities. In a face-to-face tutorial this is not so problematic. However, it is difficult in a large group for students to have the opportunity to both express their conceptual understanding and receive feedback. In a technology-based environment, the challenge is to create facilities that support interaction. We need to consider how to design features that will support the interactions that the Conversation Framework suggests between the student and the teacher. In some situations we might like to see immediate feedback on a student's efforts, however, asynchronous communication is sufficient for many purposes, and can provide more time for the reflective and planning activities that are an important part of the teaching and learning process. It is the quality of the feedback that is of most importance to the student. The feedback needs to be focussed on building conceptual bridges between what the student has expressed as their understanding and the ways in which the teacher hopes the student will progress in their understanding.



Internal activities are those that involve processes not directly observable. These kinds of activities are perhaps more difficult to transform into design elements, as they depend very much on the individual's ability to engage in metacognitive activities such as reflection, and planning. These processes form the core of what constitutes effective learning. Here the notions of surface and deep approaches to learning as discussed in the previous chapter reflect how these processes influence our interpretation of what is being asked of us in learning, how we adapt our approaches based on our interpretation of the task demands, and how critical it is for the teacher to set and adapt tasks that will support conceptual learning.

<b>Student</b>	Reflects on interaction using conceptual knowledge Further adapts action plan
<b>Teacher</b>	Adapts experiential task to help student experience the concept Teacher reflects on student interaction to begin new dialogue

*Table 4 Internally-focused teaching and learning activities*

The designer faces a difficult and challenging task in developing strategies that will support these activities, particularly when working in a medium that is not capable of gathering data that can be interpreted at a level of analysis that serves the needs of the learning situation. And indeed most of the kinds of technology-based teaching environments that are developed rarely represent the kind of adaptation based on reflection that the model inspires. We are all familiar with multiple choice tests that ask for input based on a pre-set list of options, for which pre-determined feedback has been developed. The adaptation is in the clever design of the feedback, not in the ability of the test to adapt to the input of the individual student.

Tables 3 and 4 can be interpreted as design specifications, and if one were to develop a computer-based learning system, these items would form the high-level functionality of the system. I used the model for helping to identify the kinds of elements required for design, and in structuring the interaction between the student and the learning materials. The teaching package was designed to address as many of the design specifications as possible within the constraints of the practical design task at hand. In the case of the geological mapping materials, the constraints represent common difficulties experienced by all designers, i.e. limited time and resources. The timing of the development of the materials was constrained by the availability of students to use and evaluate the materials. There was thus a short time



window (2 months) to develop the materials before the students would see them at the residential school for the first evaluation session. Resources were limited to one designer (me) who was assisted in review of content by the two tutors who were to participate in the residential school session.

In response to the reality of the constraints, it was decided to develop print-based materials as the availability of equipment and programming time were not amenable to other options. This decision put quite severe restraints on the opportunity for the students to interact sufficiently with the content in the manner outlined in the Conversational Framework above, although they involved the normal kinds of constraints on a course team. The design of the geology teaching package relied on the clever design for creating feedback, using the transcript data as the basis for developing feedback that would stimulate reflection. However, the teaching package did not adapt or reflect on the students' experience as it was not built in an interactive medium. However, later in this chapter, our discussion will include an account of how the model design specifications listed above were instantiated into design elements.

## **5.2 Building a Design from Phenomenographic Data**

Although the design process is non-linear and iterative, a process model summarizes the overall design, and can be generalized to any topic. The main purpose for articulating the process is to identify where data from studies inspired by phenomenography might best fit in the design.

- An initial content analysis provided the focus for selecting a topic for the phenomenographic study,
- The analysis of student transcripts in the phenomenographic study (the detailed content analysis) provided initial categories of conceptual difficulty,
- The categories of conceptual difficulties provided objectives for the learning materials,
- The objectives provided the basis for determining the assessment items for the learning materials,
- The assessment items provided the basis for developing the learning activities,
- The feedback was derived from the student transcripts and explanations from tutors provided during the content analysis phase, and
- The sequencing of the content was determined from the level of difficulty of the learning activities



The above is not a procedural development model, although logical dependencies between elements in the process exist, for instance, assessment items follow fairly directly from the determination of aims and objectives, that is, one should assess what one has aimed for the student to learn. It is intended to show the process used to integrate the results of the pilot study presented in the previous chapter in the design of the geology learning materials.

Through the analysis of student transcripts, the needs of the learners are discovered in relation to the particular task or problem having been developed as the object of study. In the case of geological mapping, students revealed many difficulties in their ability to interpret maps, thereby providing a fairly precise needs assessment for the group of students studied.

As much as possible in this chapter, samples of design templates and ideas that eventually became the teaching materials will be used to demonstrate how the phenomenographic study data was integrated into the eventual teaching package. In addition, samples from the final teaching package will be used to demonstrate instantiated design strategies. The remainder of this section details how the phenomenographic study was used in each stage of the design process.

### **The Expert Content Analysis**

Content analysis in analytical instructional design terms is the process of determining the type of content to be taught, and structuring the content in relation to its type (procedural, conceptual, cause and effect). There are many methods for carrying out a content or task analysis. (Merrill, Li, & Jones, 1990; Tennyson & Elmore, 1993; Reigeluth, 1983a). The end result is typically a logical hierarchical or networked arrangement of topics or tasks according to an expert view of the domain.

The analysis of student transcripts in the pilot study described in Chapter 4 constituted a specialized content analysis that described the psychological interactions between the student and the content, in contrast to a more traditional content analysis, focused on the interpretation of the content through the eyes of the expert. This distinction is crucial in understanding how to integrate a phenomenographic approach to instructional design.



The data derived from student experience is qualitatively different from the data derived from the expert. As discussed earlier, there are general distinctions between the way in which novices and experts approach problem solving (Chi et. al, 1988). Most notably, experts perceive large meaningful patterns in their domain and spend more time in an initial qualitative analysis process than do novices. Specific examples of this kind of data were presented earlier and included biology medical students' conceptions of natural selection, economics students' conceptions of the law of supply and demand, young children's conceptions of numbers, and chemistry students' conceptions of the mole concept. In each case, the results provide a view of the content that could not have been derived from an expert, precisely because an expert is one who expresses conceptual views that are consistent with well-accepted ways of viewing a phenomenon within a particular discipline.

However, a content analysis based on an expert perspective on the domain is essential to instructional design. In the current design context, the analysis served to develop a high level acquaintance with the topic area and to determine the scope of the study. I was a learner and a designer simultaneously; a situation that occurs frequently if one is a professional instructional designer. This is in contrast to some phenomenographic studies, where the topic of study is one that is well known to the researcher (Lybeck, 1988; Ottosson, 1987). However, for those where the researcher is not a content expert, the standard practice is to use an expert as consultant, as here. The instructional design effort is also a research effort, in which the instructional designer is a researcher and learner and the object of research is both the qualitatively different ways in which students express their understanding of a particular topic or phenomenon as well as coming to understand the expert's view of the structure and significance of the content to be taught.

In a discussion of the data collection and analysis process in phenomenography, Marton and Booth (1997) refer to the role of the researcher as learner;

*Remember that in discussing the phenomenographic research effort we are considering a learner (the researcher) learning about a certain phenomenon (how others experience the phenomenon of interest) in a situation (the research situation) that is of her own molding or structuring. That molding or structuring, as in other cases of learning, has an effect on the outcome of learning, both for the researcher (what she is able to bring out of the research effort) and of the people being studied (what they are able to reflect on in the research situation).*

The purpose of the initial content analysis was to identify and define the concepts associated with geological mapping interpretation as required by the course. The analysis method consisted of reviewing course and tutorial materials, whilst simultaneously consulting three experts in geological mapping; a tutor on the second-level geology course, the lead course tutor on the same course, and a member of the geology faculty who had carried out an evaluation of an earlier second-level course in geology. Discussions with the experts focused on asking them to identify particular areas of difficulties that students demonstrated, and through these discussions it was possible to select a reasonably rich and manageable scope to proceed with the phenomenographic study. The following is an excerpt from the initial content analysis, consisting of a list of concepts, some notes that demonstrate an early consideration for a focus for the phenomenographic study, following the consultations as above and my attempts at a number of map interpretation tasks myself.



---

What is involved in interpreting and transposing a geological map to a topographical profile?

Concepts seeming to be required

Dip	formations	fault
anticline	beds	fault plane
axial plane	bedding plane	fault line
folds	lithology	syncline
unconformities	extrusion	
thrust faults	strike	

There may be some confusion about what the geological map represents.

Maps are representations of known places.

Topography: geographical features of a land surface; hills, valleys?

Geological maps show a plan view of the solid rocks which would be visible at the Earth's surface if all the vegetation, soil and buildings were to be removed

**Ideas for carrying out the interviews**

What is involved in interpreting this plan view of a rock formation, and then transposing it to a side or cross-section view? Some of the problems students may be having are how to interpret slicing through the picture.

They could be thinking they are slicing a piece off the top of the map They could be just turning the map 90 degrees

It seems to me that there is a preponderance of definitions and terminology in the maps block which doesn't always happily get synthesized. For instance, the concept of topographic profiles is introduced quite early (and there are additional resources the student can access to get more information), but much later in the block the student is introduced to the concept of structure contours, are told that structure contours have exactly the same properties as topographic contours..... "What is the difference and why is the difference important?"

---

*Table 5 Initial Content Analysis Planning Document*

This planning document served as a benchmark for my own understanding of what was involved in interpreting a geological map. The last paragraph in Table 5 is a statement about the organization and sequence of the materials in the particular module (BLOCK 1) that the students were studying to learn about map interpretation. It indicates a reflection on the

confusion that can arise from the presentation of terminology that is not well synthesized for the student.

The process of coming to understand how to interpret geological maps during this phase provided a constant list of questions for the geology tutor, who through her explanations, helped to build some of the early ideas for learning activities and feedback that would be eventually developed in the teaching package. As a result of these consultations, a study idea emerged that would focus on how students interpret the problem maps used in their course work on the second-level geology course. The topic was selected because it represented a conceptually difficult task, but one that the instructors thought was a reasonable scope for an interview session of about an hour. I was particularly interested in pursuing this topic for two reasons: 1) the map interpretation task seemed difficult and 2) the instructors were puzzled as to why students had so many problems and did not seem to know how they might help. Thus, the initial work involved in building this rather ad-hoc initial analysis led directly to the development of the study described in Chapter 4.

#### **The Analysis of the transcripts**

By the time that the study was carried out, a good working relationship with one of the course tutors had developed. She provided extensive input and advice throughout the process of determining the kinds of materials to be used in the study. So even though this chapter appears to be in a logical sequence that followed-on from the study, there were many pre-study design activities and reflective activities that resulted from the development of the relationship with the tutor. In previous design enterprises, my experience with working with domain experts had an element of teacher-learner interaction, where my naïve content understanding usually focussed on my own difficulties with understanding. In the current design, the experiences of the learners provided the backdrop for all the questions I would pose to the experts, as I attempted to come to some understanding of the material not only through my own attempts but by placing myself in the centre of the particular difficulties experienced by the learners for whom I was designing. Thus, I was able to view the problem of map interpretation from the perspective of students, having worked with them as they attempted to discuss their interpretation, and later through the analysis of the transcripts. This is consistent with a second-order research perspective, where the intent is to come to understand the experience of others. The ability to engage with learners in this way enhances our understanding of the experience of learning and of the obstacles the learners face, all of



which contribute to a more comprehensive picture of the design landscape that is not available if we limit our interactions to the first order perspective of the expert view.

As I went about interviewing the students I was aware that they considered the experience to be quite important, and they mainly appeared to appreciate the opportunity to participate and talk about their experiences, even when the nature of their explanations seemed contradictory or ill-formed. This was a great contrast for me compared to interviewing experts who were concerned about the presentation of their ideas and often annoyed with questions about content that they had difficulty in understanding how to answer. This is likely because the kinds of questions instructional designers ask are from a point of view that is either naïve with regards to the content or from a point of view that an expert has not experienced. What I learned from the students was that they wanted to explore the ideas and felt comfortable with being wrong. This realization motivated me to want to design something that could counteract the difficulties they were experiencing. It was a first-hand experience with the very students for whom the design would hopefully speak, and I believe other designers who would participate in such studies would be motivated in much the same way, and perhaps with more creative and interesting results. Having data derived from student interviews also helped to explore a variety of issues with experts such as teaching practices and strategies that might help to overcome these difficulties in light of the evidence that current practices were insufficient for these students.

### **Design Elements**

The design process involves a complex iterative set of activities with many elements interwoven into a fabric of meaning for the designer, as we have seen in the above sample of a working design document Recall the iterative process model presented earlier, noting the items of interest are in **bold**.

- An initial content **analysis** provided focus for selecting a topic for the phenomenographic study,
- The analysis of student transcripts in phenomenographic study (the detailed content analysis) provided initial categories of conceptual difficulty,
- The categories of conceptual difficulties provided **objectives** for the learning materials,
- The **objectives** provided the basis for determining the **assessment items** for the learning materials,



- The **assessment items** provided the basis for developing the **learning activities**,
- The **sequencing** of the content was determined from the level of difficulty of the learning activities, and
- The **feedback** was derived from the student transcripts and explanations from tutors provided during the content analysis phase

Up to this point the discussion has focused on the first two activities. We now will focus on individual elements and attempt to show how each was handled in terms of the input from the phenomenographic analysis in the remaining design activities.

### **Assessment Items**

The design of assessment items follows logically from the development of objectives, and the two should have a coherent relationship, with assessment items becoming the driving force for the development of learning activities in the design process. Assessment is a critical component of the teaching and learning process. Terms that are sometimes used interchangeably are evaluation, testing, and performance measurement. Assessment is the process of establishing effective and valid ways for evaluating what the learner can do or knows and can enable the monitoring of the learner's progress in learning what your course is designed to teach. Assessment of student performance is the process of establishing what constitutes competent performance and determining what method to apply that best allows the performance to be measured. Ramsden (1988) provides an extensive discussion of the relationship between assessment and approaches to learning. (See Chapter 4 for more detail) Briefly, he explains that the demands set by assessment (or set tasks) as interpreted by the student directly affect the way in which the student will approach studying for that assessment. For example, if a student perceives that the assessment will test his ability to use formulas to solve problems, he will concentrate on memorizing formulas. In contrast, if he perceives the assessment to be about selecting a problem-solving approach (which may also include selecting the correct formula), he will attempt to understand how to interpret problems.

Testing an isolated skill or a retained fact does not effectively measure a student's capabilities. In order to evaluate what a person has learned, an assessment method must examine his or her problem-solving or decision-making abilities. This is sometimes referred to as authentic assessment. Authentic assessment presents students with real-world challenges that require



them to apply their relevant skills and knowledge. The major advantage of this type of assessment is that it requires students to develop responses rather than select from a pre-determined list of options, which in turn requires the student to be operating at a much higher cognitive level. Authentic assessment tests the problem-solving abilities of the learner and not just their knowledge or ability to recognize a correct answer as can sometimes be the case when one implements multiple-choice instruments for assessment.

Below is an excerpt from an early lesson plan. In this early stage, the design activity was focussed on the development of assessment questions and tasks that might be set to determine how well the students understood the concepts being presented. However, the following items were discounted because although they succeed in testing the objective, as an aspect of the teaching they would have contributed to additional difficulties in sorting out the difference between topography and geology. It is not often that one sees the 'wrong' design elements, however, this chapter is concerned with how the design proceeded and in doing so should demonstrate the iterative nature of the process.

- 1. What geological processes are primarily responsible for present-day topography?*
- 2. What kinds of information about the geology can you deduce from topographical features (such as valleys, present-day streams)*

The reason that the first statement is misleading is that topographic features are a result of the dynamic relationship between geological processes, such as folding and faulting, and weathering processes such as erosion. The statement that only geological processes have an **impact** on topographic features and is therefore a misconception and inappropriate as an assessment item. From this you can see the iterative nature of the design process, one that evolved as the knowledge of the designer as learner evolved. Ensuring the correctness of the material involved constant consultation with the domain experts. However, my learning status provided a **perspective** on the material that experts would likely not experience. I found it quite **easy** to relate to the difficulties that students experienced, and I was able to ask questions of the experts as a learner that they would not likely ask amongst themselves. These progressive clarifications are an essential part of the design process, and help us to more clearly articulate the nature of the content that we are trying to teach.



It is relatively simple to test low level facts or learned definitions and procedures, but to test for conceptual understanding requires the researcher or the teacher to develop questions and tasks that will demand that students apply their understanding of a topic. Marton & Saljo (1984) have shown that students will demonstrate their competence according to how they interpret the demands of the task (the assessment task). If students believe that the assessment is going to require them to gain a deep understanding of the material, they will approach the learning task with strategies for acquiring this level of understanding. These strategies might include asking questions for clarity, attempting more difficult exercises to test their understanding, and seeking additional resources such as additional reading lists. Similarly, if they perceive the learning task as one of acquiring simple factual knowledge, they tend to approach learning with the intent to memorize simple factual knowledge. It is useful, therefore, for students to be told, and reminded during the course, on what basis they will be assessed.

Ramsden (1992) provides a comprehensive discussion of potential approaches for improving assessment, and thus helping students' approach learning in a deep and meaningful way. He says;

*Too much assessed work leads to superficial approaches; clear indications of priorities in what has to be learned, and why it has to be learned, provide fertile ground for deep approaches.*

(Ibid.Pg. 188)

Thus, the development of assessment items and methods must genuinely reflect that there is no hidden agenda, and that the goals set out in the course are reasonably matched to what the learner should expect will be assessed.

In the design of the geological mapping materials, each objective formed the basis for a learning activity, and each learning activity had an assessment component in the form of a practice item, thus the consistency in the design process provided the learner with the priorities for what was to be learned so that it was clear what needed to be done. Each of the learning activities used simple visual representations to illustrate the key concepts, in one case demonstrating a progression of changes in topography and how this change did not affect the geological structure (See Figure 5) Using this approach, the student was encouraged to apply



a deep approach by considering the visual evidence in the context of the textual explanation, to predict how and why the representation might change, and to reflect on how the sequence fit within the overall concept.

Students were encouraged to think about the concept of dip from a different perspective than they had previously encountered. From the phenomenographic study, we knew that they had difficulty in visualizing how a cross-section would look based on the dimensional plan view. One of the exercises provided the opportunity to first see the cross-section, and then to see how the plan view compared.

### **Aims and Objectives**

The design of learning materials should always begin with a statement of learning aims and objectives. The point of learning objectives is twofold, to determine whether the teaching intervention as designed has actually had any impact on student performance and to suggest potential activities in which students will engage in order to meet the objectives. The process of establishing aims and objectives is an iterative refinement of a general idea to the eventual articulation of a set of statements that set out actual student performance. Following the analysis of the student transcripts, aims and objectives were developed based on the difficulties students revealed in the map interpretation task. In the phenomenographic study, there were three main categories of difficulty identified. Recall that they were;

1. Students confuse the relationship between present-day topography and sub-surface geological structures.
2. Students have difficulty in determining whether a sub-surface structure is an anticline or syncline.
3. Students have difficulty in visualizing three-dimensional sub-structures.

In the analysis of student transcripts, students demonstrated familiarity with topography and used that experience to interpret the outcrops on the plan view as though they represented (topographic) contour lines. Students demonstrated the difficulty they experienced in the relationship between topography (i.e. rivers) and geology (i.e. rocks) in the following excerpts.

S4: The river is going down, but the rocks aren't.

S6: I notice the streams which are useful for the gradients, but I have to be careful there since sometimes I confuse myself with the dip of the rock and the gradients of the ground.

These transcripts and others provided the basis for new objectives that were directly related to the difficulties revealed by the students. The process of developing the objectives was rather straightforward. Once the transcripts had been analysed, it was a matter of formulating an objective that had as its focus the problems identified and having been achieved by the student, would overcome the difficulty described in the category.

The final list of objectives for the teaching package follow.

Given a simple geological map, you will be able to identify and explain how V patterns indicate dip direction, and provide clues for interpreting underlying geological structures.

Given a simple geological map, you will be able to identify the visual features that indicate the presence of fold structures.

Given a visual representation, you will be able to discriminate between antiforms and synforms.

The following objectives were developed by the Open University course team and serve as a comparison in order to illustrate the input from the analysis of student transcripts to the process of defining objectives;

*Interpret the geological history of an area containing folded strata and unconformities from map data.*

*Identify dip directions on geological maps from the stratigraphic succession, using outcrop patterns, including V-ing strata.*



*Identify simple folds on geological maps from outcrop patterns and the stratigraphic succession.*

*Prepare sketch cross-sections and draw accurate geological cross-sections across geological maps showing simple arrangements of tilted and folded strata and unconformities.*

(The Open University course objectives for the section on cross-sections, from Objectives; Sections 3 and 4, Block One Geological Maps)

The objectives developed based on the student transcripts are more precise than the objectives provided to students in the Open University course materials, which may explain why students continued to struggle with the ideas. The differences between the objectives I have developed and the OU objectives presented above may appear subtle. In order to make explicit the differences, one objective from each set will be taken apart and analysed to make the point. Again the OU objective is:

*Identify dip directions on geological maps from the stratigraphic succession, using outcrop patterns, including V-ing strata.*

This objective makes assumptions about what the student might already be able to do, even though the mapping part of the course is the first introduction to these concepts that the student encounters. We saw in the study that very few students were able to understand much about stratigraphic succession, and that the students attempted to apply the rules without understanding the basis for interpreting V-patterns, rendering the rules as meaningless. Therefore, although this might be a very reasonable high level objective, we found from analyzing student transcripts that there were many concepts that they had not come to grips with, and this objective was not appropriately placed in terms of its level of performance for this group of students. Again, we compare the above to the objective developed as a result of the phenomenographic analysis process

*Given a simple geological map, you will be able to identify and explain how V patterns indicate dip direction, and provide clues for interpreting underlying geological structures.*



This objective is precisely focussed on V-patterns and their role in helping the student to interpret geological structures. We found in the study that firstly, students could not even identify the existence of the V-patterns to which the OU objective refers. We also found that students needed to be reminded that these V-patterns were clues so that they would not assume some kind of cause and effect relationship about surface and sub-surface structures.

The phenomenographic study revealed the conceptual difficulties that persisted for many students. As shown, the development of objectives with input from phenomenographic analysis provides more precise statements of what we need to aim for in our designs. As objectives form the starting point for development of learning materials, the inclusion of phenomenographic data provides clarity to the task, and confidence for the designer that the materials to be developed will have a strong empirical basis that is consistent with student needs.

### **Learning Activities and Feedback**

Learning activities or practice exercises are the heart of the learning materials. Their purpose is to provide an opportunity for the students to interact with the content, and to compare their understanding with the model understanding, and to offer explanatory feedback that will help them to understand the nature of their misunderstandings. In this section, a sample learning activity provided in the teaching package is presented and discussed. This discussion will focus on feedback as a key component of the design, and refer back to the Conversational Framework to determine how well the activities represent the requirements of that model.

There are many different kinds of feedback (informative, corrective, encouraging, directive, hints, clues), but they all have the aim of providing guidance to the student at the point at which they have given some kind of response in the teaching-learning process. There are many interesting issues surrounding how to develop feedback, how to determine when to provide it, and the form most appropriate given the task set to the student. In Laurillard's Conversation Model, feedback is central in the iterations between the teacher and the learner, whether the feedback is provided on particular actions, or whether feedback is provided in the form of a new task as a result of reflection on a student's action or demonstration of their conceptual understanding.

The first step in developing feedback for the learning activities was to re-visit the student transcripts to build explanations for incorrect responses that would relate to the kinds of



difficulties students experienced. Feedback was also constructed from notes taken during interviews with tutors that took place as part of the initial content analysis. Feedback in the final design consisted of a correct answer and solution that the student could use to self-assess their answers and solution. This is not an ideal implementation of a feedback element, because it is not interactive and the student can not ask for more or alternative explanations. However, because the feedback was based on the students' transcripts, it had at least the advantage of addressing potential difficulties that students might experience in trying to interpret the map that had been found with other, similar students.

The following sequence of pages from the teaching package demonstrates the kind of feedback implemented in the design. In order for the feedback to make sense, figure 5 shows the page where the student is provided with an example concept. This shows the student how a geological structure in cross-section view appears in map view and can change as continuous processes alter the appearance of the structure where the strata are visible on the surface.

### 3.2 Learning Exercise 2: Understanding Continuous Processes

The following series of diagrams show the effects of erosion over time on an antiform. Look carefully at each of the stages and how each stage would be look on its corresponding geological map.

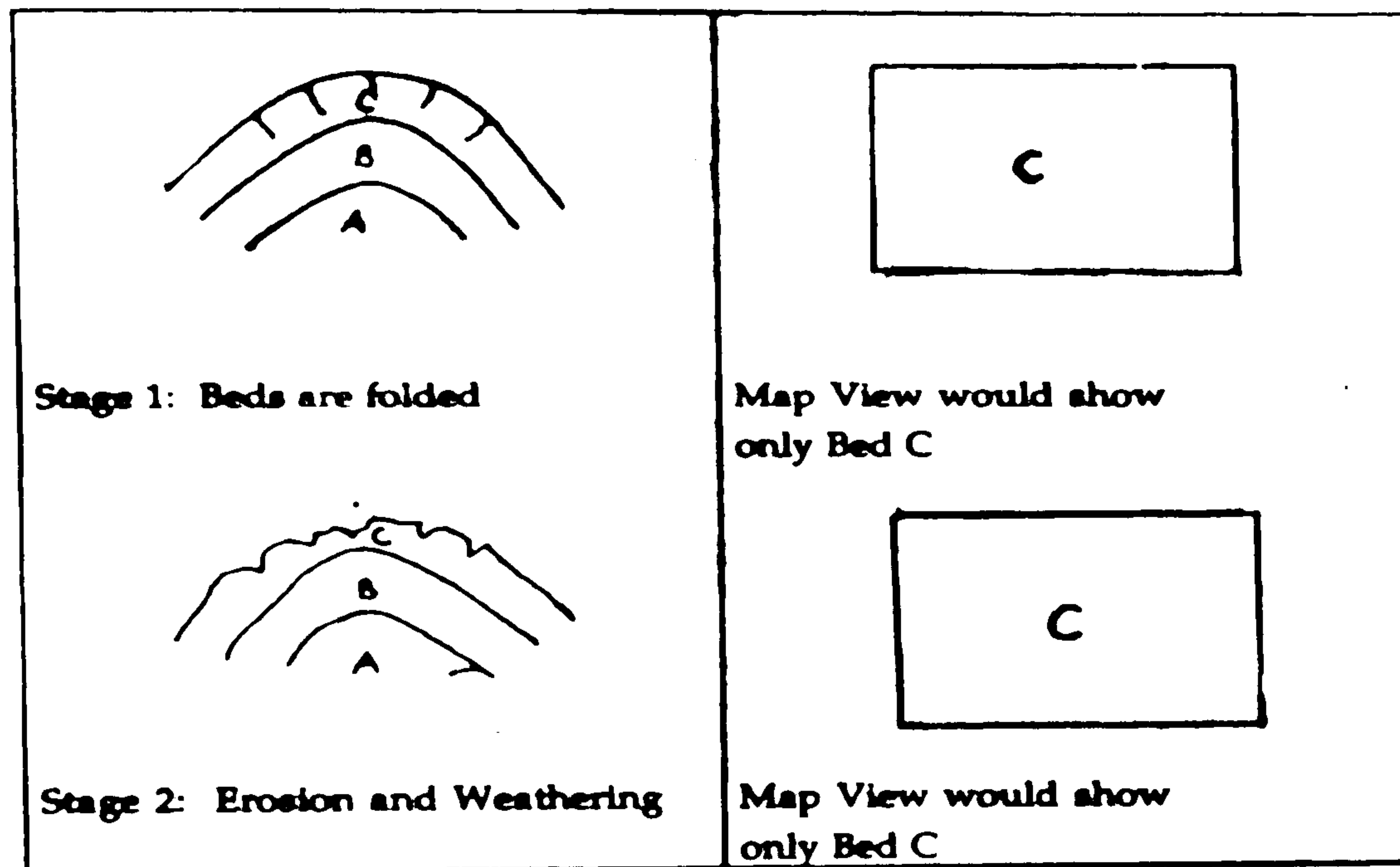


Figure 5 Learning Activity Providing Example of Concept



Following the example, the student is asked to try to interpret how the cross-section would look at later stages of geological time in the figure 6.

**Instructions**

Fill in the letters of the formations you think would appear on the Map View for stages 3 and 4.




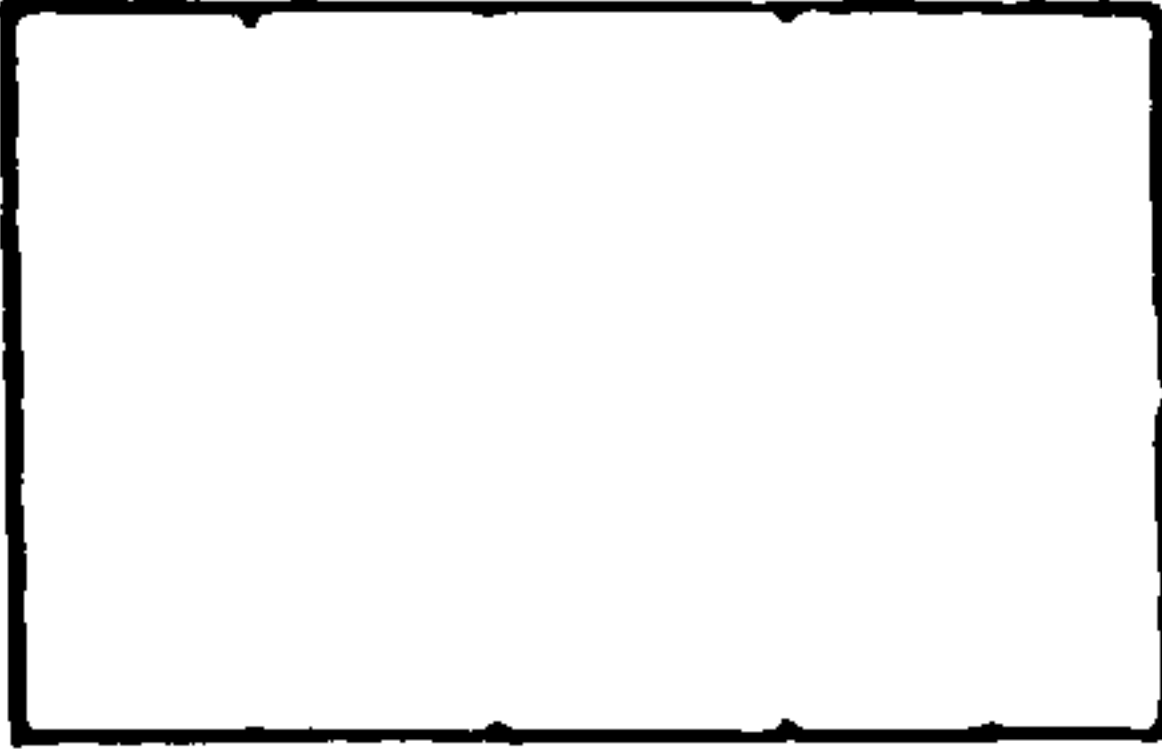
	
Stage 3: Erosion and Weathering Continues	Map View now shows which beds?
	
Stage 4: Erosion and Weathering Continues	Map View now shows which beds?

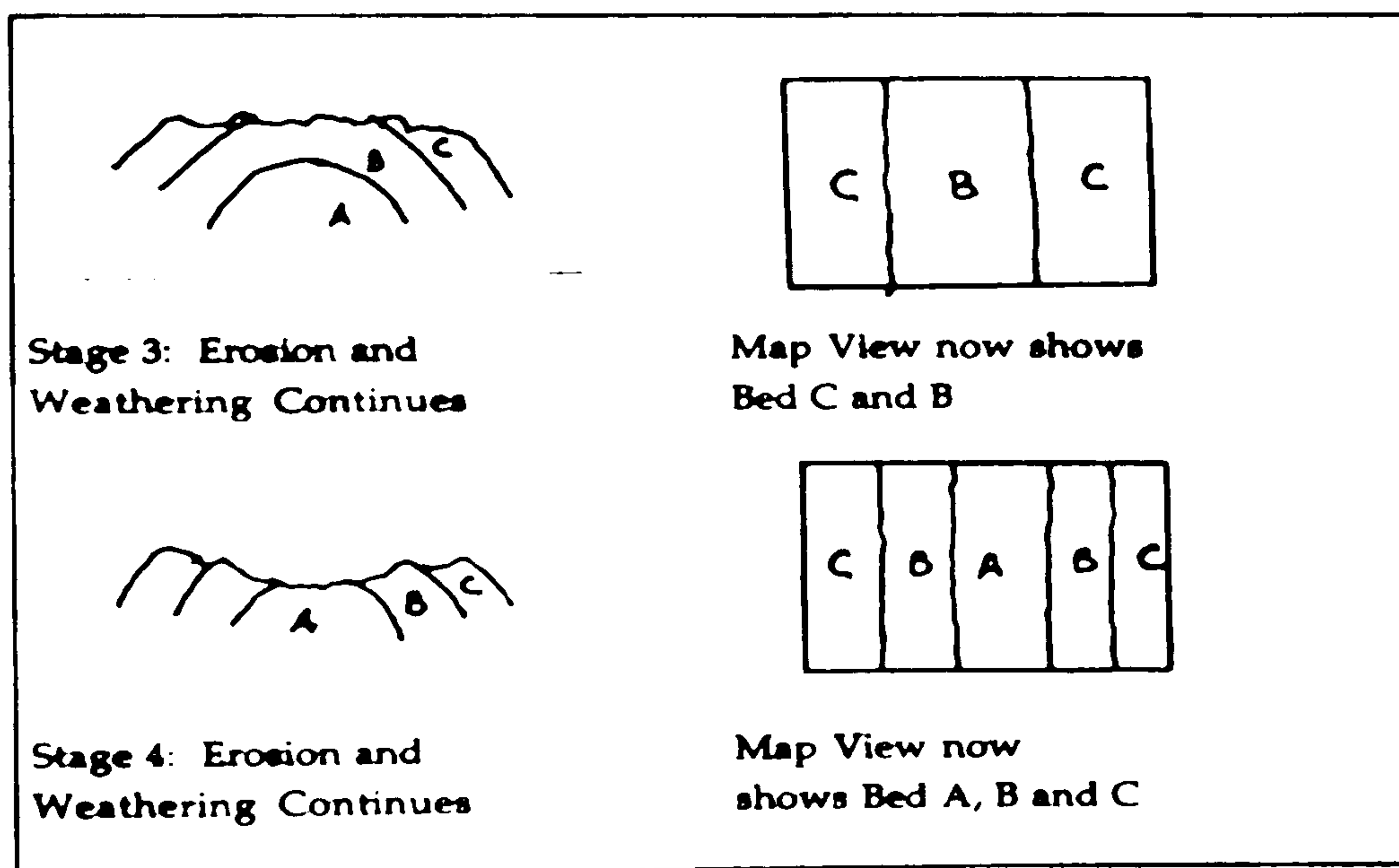
Figure 6 Learning Activity Requesting Student Interaction

And finally, the feedback in figure 7 for this learning activity consists of an explanation of the purpose of the diagram with the correct interpretation. The explanation attempts to convey the idea that surface processes have an impact on the appearance at the surface, but that the structure of the geological form remains, that is, the structure is still an antiform although it is eroded.

**3.2 Feedback**

The diagram illustrated the surface processes which may happen as an antiform develops. In Stage 1, the horizontal strata begins to buckle because of lateral pressure into a series of developing antiforms and synforms. We are looking at an upfolded section of this development.

As the antiform develops, the beds weaken across the crest, making them prone to erosion. Bed C is gradually eroded, exposing Bed D, which in turn is eroded away exposing Bed A, in the middle of the antiform. If some beds are more resistant, they will form steep slopes which face each other across the middle of the antiform, leaving a topographical low area in the middle.



**Summary**

You have seen the effects of erosion on an antiform over time, and how the map view of the formation changes as beds become exposed at the surface.

*Figure 7 Feedback Sample for Learning Exercises*



## **Summary**

The above sequence of diagrams from the learning materials demonstrates the way in which feedback was integrated in the learning activities. The limitation on the feedback was that it did not allow an iteration of sequences as suggested in the Conversational Model. However, there is a glimpse here of how feedback can be developed based on our knowledge that particular conceptual difficulties exist, in this case that students have difficulties in understanding the relationship between topography and geology.

## **Sequencing**

Sequencing is the ordering of content for presentation to the student. Sequencing is a natural progression from carrying out a content analysis and developing a content structure in instructional design practice. As discussed in Chapter 3, sequencing of content follows a determination of some kind of organization of learning objectives, depending on the theoretical approach one decides to follow. There are two levels of sequencing to consider, the macro-level arrangement of topics that make up the overall structure of a course and the micro-level arrangement of strategies that make up the inter-topic level interactions.

Merrill (1983) refers to micro-sequencing decisions as instructional transactions and his CDT (Component Display Theory) provides specific prescriptions for sequencing a series of instructional strategies at this level. For example, for an objective that requires the learner to FIND A PRINCIPLE according to CDT, the subsequent prescription for sequencing instructional strategies would be to present examples and non-examples first, followed by the presentation of the defined concept.

In the Conversational Framework (Laurillard, 1993), the sequencing of content involves sequencing specific kinds of interactions between the teacher and the student. The content of the interactions changes in complexity as the student's knowledge progresses. The patterns of the iterations evolve, where there may be less need to provide the teacher's re-conceptualization directly as the student becomes more expert, and to focus more on adapting the difficulty level of the tasks to perform. This is related to the notion of cognitive scaffolding and fading, where the gradually the teacher reduces the amount of support and shifts more and more of the control to the learner (Burton, Brown, and Fischer, 1984).



Reigeluth's Elaboration Theory (1983) is more concerned with macro-level organizational strategies, that is, sequencing of topics according to his notion of a specialized top-down arrangement that begins with a high-level representative application-level topic and progressively adds detail and complexity.

The Open University geological mapping course materials followed a simple to complex sequence, introducing concepts in a simplified way to begin with, then elaborating on them as the materials progress. However, in order for this kind of approach to help the students to integrate new material into existing material, there is a need to summarize and synthesize the concepts in relation to one another, an idea that comes directly from Elaboration Theory (Reigeluth, 1983b). This approach has some promise, as long as one accepts the idea that a traditional content analysis is insufficient to serve as the basis for identifying the concepts and related concepts that need to be summarized and synthesized. Phenomenographic studies provide the student's conceptual understanding, their alternative (to the expert) view of the structure of the content, and as such, can help to focus sequencing decisions, particularly at the inter-topic level. The current design dealt with a limited scope and therefore will only address sequencing at the topic level. However, in Chapter 8 where the implications for the results of the findings of the thesis are discussed, further elaboration regarding the application of phenomenographic studies to larger-scale design efforts will be addressed.

There is no analytical way that one can come up with the type of information discovered in phenomenographic analysis. It is an empirical result of analyzing student experience, which gives you this insight. It follows then, that a generic approach to sequencing may not necessarily provide the 'right' organization of learning activities to meet the particular needs of students. Recall the conceptual difficulties that were revealed in the study.

1. Students confuse the relationship between present-day topography and sub-surface geological structures.
2. Students have difficulty in determining whether a sub-surface structure is an anticline (antiforms) or syncline (synforms).
3. Students have difficulty in visualizing three-dimensional sub-structures.



The approach to sequencing was to develop learning activities to address these difficulties and then to order the presentation of the activities by their difficulty level. The following lists the learning activities in order of their presentation sequence ;

- Comparing Synforms and Antiforms
- Understanding Continuous Processes
- Determining Dip Directions
- Dip Directions From Cross-Sections
- Interpreting V's

The above represents a simple to complex sequence based on the conceptual difficulties student's demonstrated in the phenomenographic study. In the first learning activity, learners are given a fairly simple visual discrimination task to distinguish between synforms and antiforms. Understanding Continuous Processes was described in some detail in the last section on Learning Activities, the presentation was fairly simple, and did not rely on geological knowledge. The third exercise on Dip Directions and the fourth exercise on Dip Directions from Cross-Sections takes the learner much further into understanding the mapping conventions and the ability to make interpretations of these conventions. And the last exercise presents the most difficult objective that was revealed in the phenomenographic study, to interpret how v-patterns on maps provided clues to the structure of the geological formation.

Reflecting now on the sequence, I note that the first three exercises do not represent a pre-requisite ordering, i.e., the learner does not need to learn to distinguish between antiforms and synforms in order to understand continuous processes, nor in order to understand how to determine dip directions. A better ordering may have been to start with continuous processes to set the stage for students to learn about the other concepts within the context of an important principle of geology, that of continuous and dynamic processes over time.

Inter-topic sequencing followed the following structure. It is based on the need for iteration between the student and the teaching materials as advocated in the Conversational Framework model in the form of the setting of the task and the feedback. It also draws from Elaboration

Theory in the development of the synthesis and summary at the end of each activity and with the development of the overviews.

- List of objectives for the lesson,
- Overview introducing students to what the lesson was about (folds), reminding students about definitions of concepts such as topographic profile, and cross-section,
  - Learning exercises, consisting of;
  - Introduction to the concepts for each exercise,
  - Example(s) of the concepts,
  - Student activity that instructed the student how to carry out an activity working with diagrams and maps,
  - Feedback, a correct solution to the student activity, often with elaborative explanation, and
  - Summary, a statement of what the student has done in the activity, with a transition to the next section of the lesson.

### **Summary**

Sequencing of content has a long history in the analytical instructional design literature. (Gagné,1985; Reigeluth,1983; Merrill, 1983). Based on my experience in designing the geological mapping materials, the issue of sequencing requires additional consideration in terms of finding a rubric or scheme to follow. The analysis of the phenomenographic data perhaps requires an additional focus on this issue to make implications for a particular approach. This may indicate the need for a set of tasks that vary in complexity, where the researcher would probe learners for interpretation of the relationship between the tasks and concepts represented in the tasks. In this way, additional implications for sequencing may be drawn from phenomenographic studies.



### **5.3 New Design Elements**

The final teaching package consisted of a printed booklet titled "Learning About Folds". It is self-paced instruction, consisting of visual materials (graphics and maps) structured in a simple to complex sequence, requiring the student to gradually carry out more difficult exercises. Excerpts from the design have been provided as illustrations of the design decisions.

In the next three sections the focus of discussion will be on design elements that emerged from the analysis of the phenomenographic study that require special consideration in design decisions.

#### **Pedagogic Error**

Pedagogic error is a term coined by Laurillard (1993) that refers to errors in conceptions that students make because of the way they are taught. Laurillard uses this term to explore the idea that student misconceptions are not necessarily 'gaps' in knowledge, but are the result of mistakes in processing that have their origin in inadequate teaching materials. It is most useful in the context of remediation, where one can identify conceptual difficulties related to the way in which material had been initially presented to students.

Pre-empting pedagogic error involves first identifying the potential source of the resulting problem. As we discussed in the previous chapter, the order of presentation of geological mapping in the course may have contributed to some of the difficulties revealed in the phenomenographic study. Geological mapping was the first module of the course, so students were not very familiar with the basic concepts of geological thinking. This led, I believe to the application of a surface approach to interpreting maps, an idea that will be further explored in the next chapter on evaluation of the teaching package. In support of this, recall from the previous discussion of representations (see Chapter 3) where Lowe (1983) investigated the mental representation developed from a weather map by professional and non-meteorologists. He found that professional meteorologists were able to construct semantically based mental representations because they possessed extensive domain-specific meteorological knowledge. Non-meteorologists, however, constructed more superficial mental representations, based upon domain-general, visuo-spatial characteristics of the weather map.



He concluded that the use of diagrams in instruction may fail to bring the desired learning benefits, and that students may in fact be at a disadvantage when certain kinds of diagrams are used. He suggests that;

*...teachers may need to discriminate between different types of diagrams and see abstract diagrams as a potential learning problem in themselves rather than as a solution to those problems.*

(Ibid.Pg. 177)

This implies that as designers we must take care to ensure that if a diagram is complex and needs careful processing, then we must help students take a principled approach to understanding the meaning. Therefore, one approach for avoiding pedagogic error is to design for deep approaches to processing. The Conversational Framework elements become important in this regard, because we can try to figure out how to explicitly design for the metacognitive processes of planning and reflection that are at the very heart of the model, indeed without which the model is incomplete. However, we must bear in mind some interesting research reported by Ramsden (1992) in which he discusses unintended consequences of trying to teach deep approaches to learning. One of the studies he cites has been described elsewhere in this thesis (see Chapter 3), the study of understanding from text by Marton and Saljo (1984). As part of this study, the investigators tried to give students hints in the form of questions to answer within the text that they believed would help the students to search for meaning. The unintended result was that students focused on finding only the answers to those questions, and did not attempt to understand any other aspects of the text. They were able to recall what the passages that questions addressed were about but not the meaning of the other parts of the text. Interestingly, students seem to be very good at taking directions that they perceive will help them to accomplish a goal, but they do not necessarily generalize deep approaches to learning from this kind of experience. In fact, the opposite seems to occur and they then rely on these kinds of cues to alert them to important points to the exclusion of others.



The second investigation was carried out by Ramsden et.al. (1986) and looked at the effect of trying to train first year students to adopt study skills. The unintended results were that students reported that they perceived first-year courses to be about accumulating a lot of information and that the study skills courses helped them to achieve that goal. Clearly, the intentions were correct, but as in many cases in learning interventions, the outcomes are not necessarily consistent with the goals.

There are three possible ways to design for deep approaches to learning. The first is to set the assessment at the right level, ensuring that students understand that their conceptual knowledge is of importance, not the ability to recount definitions or formulas, or to remember factual information. It needs to be made explicit that they are to work towards developing the ability to apply their knowledge of the content. We saw for instance in the phenomenographic study that students struggled to remember rules about how to interpret v-shapes associated with the interaction between a river valley and exposed dipping geological formations. In the study I found that the rules had no meaning to the students, and they tried to apply a surface approach to interpretation by applying meaningless rules. In the design of the teaching package, I first set about ensuring that they could identify the v-shapes on the maps since it would not be possible to learn the meaning of the v-shapes unless they were first able to visually identify them. Once the students were able to identify the v-shapes, as in figure 8, the interpretation of the dip directions could then be explained.



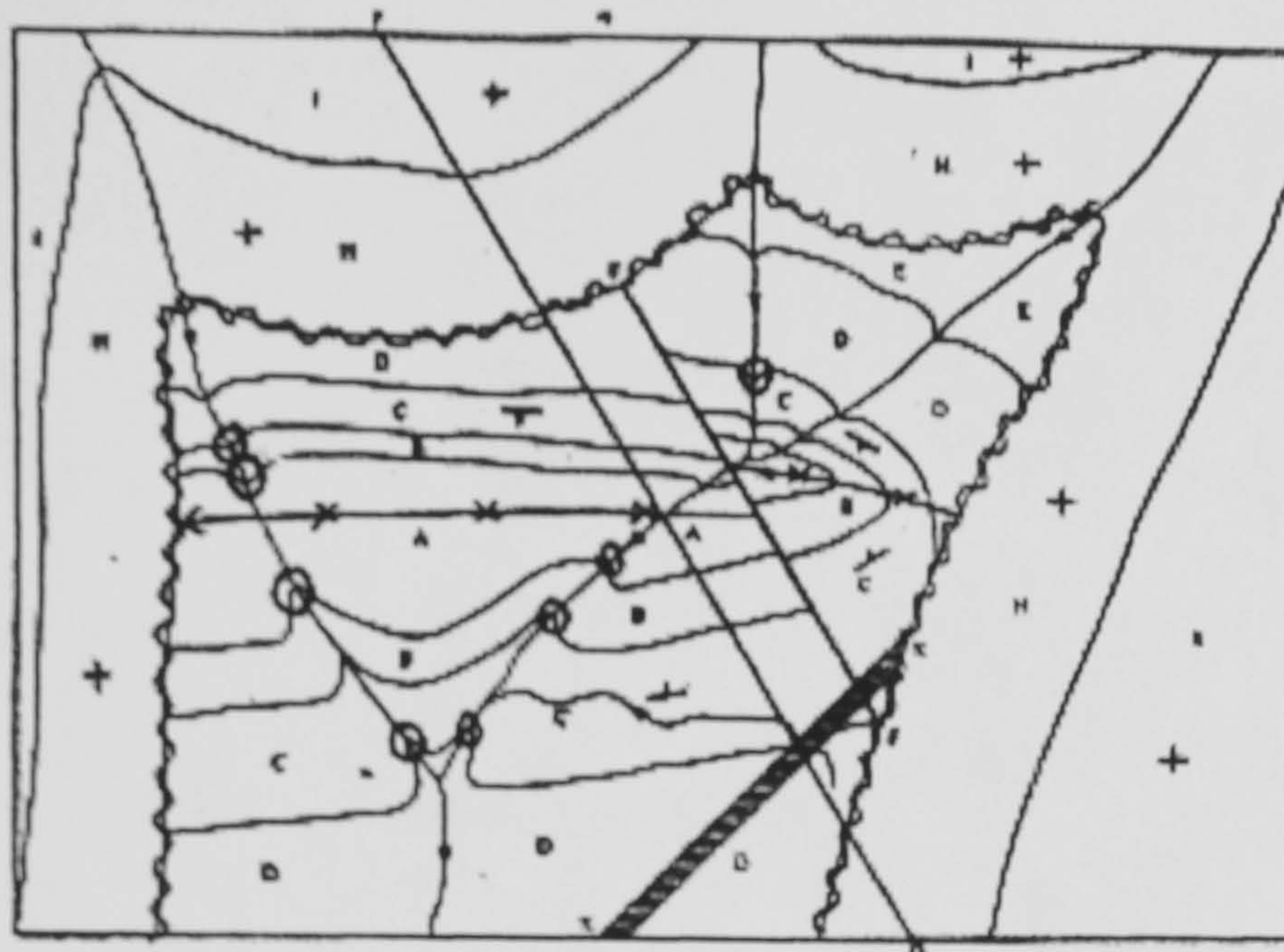


Figure 8 Expert interpretation of v-patterns on a simple geological map

Figure 8 above is an expert interpretation of the v-patterns that appear on a simple geological map. The learner was first given a map without the circles and asked to indicate the location of the v-patterns by circling them. It was critical for the learner to first identify the feature, and subsequently then learn the conceptual material related to the feature.

The second possible way to encourage deep approaches to learning is to use an idea from Reigeluth's Elaboration Theory (1988), that is to synthesize and summarize in a systematic way during the process of teaching and learning. I am suggesting a more learner-centred approach that goes beyond providing a summary of points and indicating where new material fits with old material, as is the case in Elaboration Theory. The intent is to develop learning activities that engage the learner in the process of summarizing and synthesizing what they have learned, stimulating their reflective processes. For example, in the previous chapter I discussed one student who had applied a deep approach to map interpretation. In his interpretation, he demonstrated how to link evidence to a theory, maintaining a theoretical stance and looking for either confirmation or rejection depending on how well the evidence fit. Providing an opportunity to develop this approach could be accomplished through practicing developing a summary of the history of a geological area and showing how new evidence can be synthesized with existing evidence. This idea is in line with Ramsden's



(1988) discussion of teaching strategies for effective learning in which he talks about realizing constructive engagement activities that require the students to actively find knowledge, interpret results, and test hypotheses. He contrasts this with strategies that concentrate on providing authoritative information, or teacher-generated presentations. This supports the idea of avoiding 'the technification of learning' raised by Marton and Booth (1997). The concern is to avoid manipulations of the presentation of content that focus the learner on the object to be learned and away from their awareness of the act of learning.

A third way to encourage a deep approach to learning is to directly teach students how to develop a theory, hypothesis or claim, and then to search for evidence to support it. In geological mapping this would take the form of demonstrating how a professional geologist thinks about the interpretation task by first developing an overall theory of how an area may have been formed, and then searches for the features on the map that support or refute this interpretation.

An alternative interpretation of pedagogic error could be drawn from Cognitive Flexibility Theory (Spiro et.al., 1992) which criticizes cognitive schema theories because they assume in general that domains are more simple and regular than they really are. He would attribute conceptual difficulties, such as the ones described in Chapter 4 to the practice of oversimplification, either in the representation of a domain or in the design of educational experiences. This issue will also be further explored in Chapter 9, with discussions of how a phenomenographic approach to analyzing content may be applied in support of a variety of theoretical frameworks, including constructivism to which Cognitive Flexibility Theory is aligned.

The process of identifying potential pedagogic errors involved an analysis of the design elements of the Open University teaching materials in relation to the conceptual difficulties experiences detailed in the previous chapter. The following is a list of potential sources of pedagogic errors in the original teaching material. They have been categorized into three types: Sequencing, Representations, and Mnemonics.

### **Sequencing**

As discussed above in the section on Design Elements, sequencing is a highly complex issue. The designer must determine on what basis the materials under development will be ordered,

whether using a simple-to-complex or general to detailed approach. In the Open University geology materials, the placement of mapping at the early part of the course before geological understanding had been achieved may have been one source of pedagogic error. When students have no geological theory to support interpretations, they will make use of their existing knowledge, leading to likely misinterpretations.

### **Representations**

The literature on the use of visual representations suggests that students require knowledge in order to interpret these representations effectively (Friedman, 1993; Lowe, 1983). Therefore, the use of visual representations is an important design consideration. The important point here is that the identification of the source of conceptual difficulties can provide the designer with additional data on which to make more informed decisions. The use of representations without sufficient explanation of their meaning will lead students to supplement inadequate information with their own inventions.

### **Mnemonics**

Mnemonics refers to the use of rules or reminders that help the learner to remember something. These kinds of strategies are common in the medical profession, where students are required to learn massive amounts of information. Examples include grammatical rule mnemonics, such as "I before E, but not after C". However, the use of such strategies must take into account how the learner will interpret them. They are most useful devices once a learner has acquired understanding and needs only to be reminded.

The use of rules for teaching students to interpret v-patterns on maps that were provided to students in the Open University geology course were insufficiently understood by students. Rules applied without understanding lead to an instrumental or surface approach to learning that does not encourage the student to understand the relationship between the rules.



### **Discipline Specific Terminology**

In studies of student learning (White & Horitz, 1988) it has been discovered that students have difficulty in understanding how discipline specific terminology relates to common or everyday usage, thus leading to barriers in acquiring conceptions that will lead to success. In physics, students continue to 'hold on' to everyday meanings of terms such as force and acceleration that prevent them from understanding basic concepts on which they need to build mental models of physical systems. One design strategy for overcoming these difficulties include developing glossaries that link related terms; however, the definitions of these terms need to be specifically written to make distinctions between terms that might be commonly confused. In other words, the terms need to be explicitly related to one another within the definitions so that any confusion is overcome.

In the geological mapping study, students attempted to apply their understanding of topographic formations to interpreting sub-surface geological formations. A simple approach to help them overcome this difficulty was to specifically define terminology that was commonly confused in explanations in the design of the teaching package.

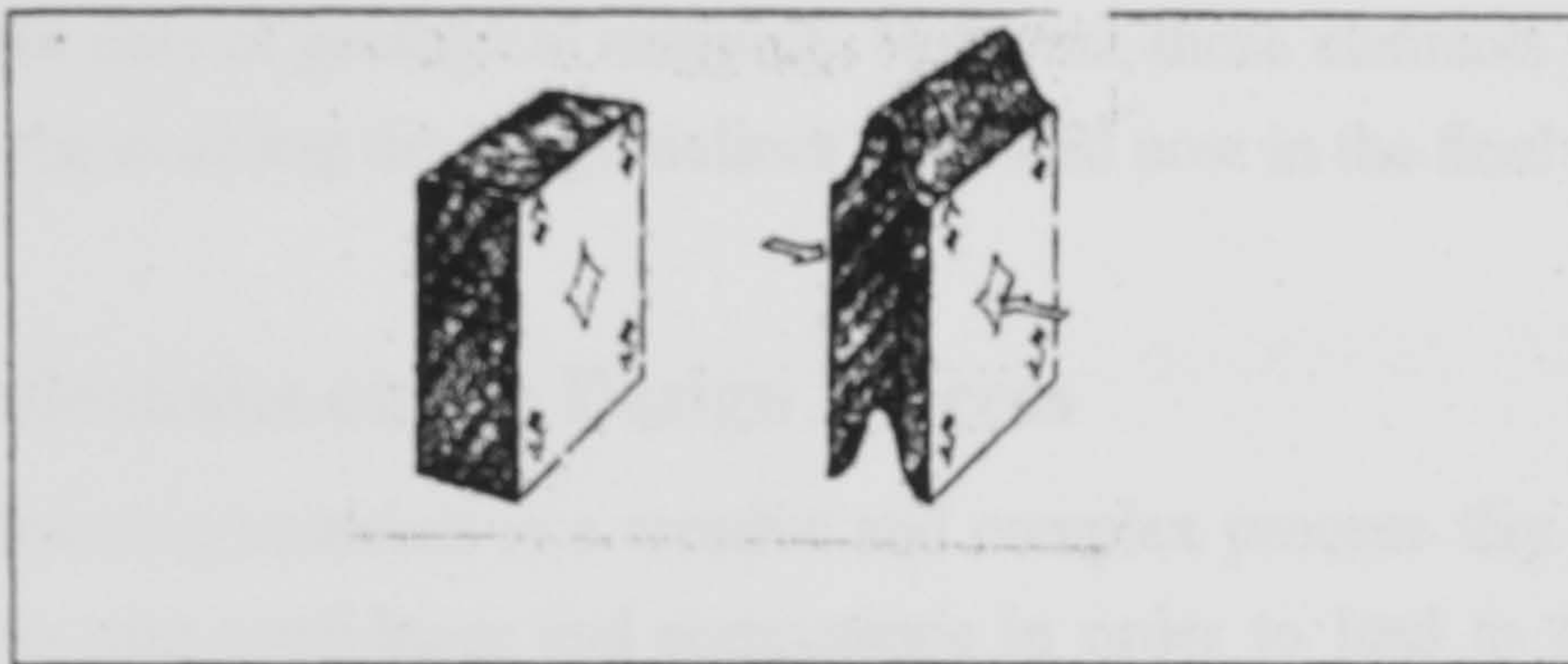


### 3.0 Learning Exercises

The remainder of this lesson is a series of learning exercises, starting with a brief introduction to a topic, followed by examples, then followed by instructions for answering questions, or working with diagrams. Once you have completed the instructions, a feedback sheet on the exercise shows a correct solution.

#### Introduction

Folded geological structures refer to the direction in which beds of rocks are sloping. Beds are folded as a result of compression by lateral pressure over time. Folds occur when rocks are sufficiently flexible to deform and depend both on the particular rock type and the nature of the deformation.



Over time, a topography develops which can reflect the underlying geological structures. As folds develop, they are subjected to weathering and erosion, and the extent to which they are affected depends on the relative resistance of the rock types; harder rocks, such as well-cemented sandstone, are more resistant to erosion than softer rocks, such as mudstones. The changes to the rocks due to erosion and weathering affect only the surface features of geological structures, i.e. the topography, but the original structure remains the same at depth. This is an important idea to remember as you are learning about folds.

*Figure 9 Sample of terminology explanation*

Figure 9 above demonstrates that the terminology associated with geological mapping is being used in a particular way. Note in the paragraph under the graphic, that topography is defined in relation to geological structures, i.e. processes such as erosion and weathering may change the appearance of geological structures where the strata is exposed at the surface, but the geological structure does not change as a result of these factors. For example, the figure above demonstrates the effect of the geological process of lateral pressure. Over time, if the strata are exposed to erosion at the surface, parts of the structure will be removed, but the original fold structure remains.



The use of terminology that helps the student to overcome conceptual difficulties is reasonably straightforward, once one has an idea of the nature of the confusion between terms or that students may be attributing more common-sense (everyday meanings) definitions that are not appropriate in the learning context. Other design approaches could include the development of conceptually related dictionaries, where terms that are easily confused or terms that have both everyday and scientific or discipline-specific meanings are linked, a distinct advantage when one is designing in an electronic learning environment.

The pilot study provided data that was used in the design of standard design elements such as sequencing, feedback and objectives. The study also yielded three new elements that were specific to the case of geological mapping. However, these elements can be generalized to be included in the evolving design guidelines discussed now in the final section of this chapter.

#### **5.4 Reflections on the Design Process**

Designing learning materials is a creative and complex process that requires many years of experience to gain confidence and competence in order to lead to good results. Systematic models such as Instructional Systems Design (ISD) can help structure the myriad of activities and decisions that a designer faces and instructional design theories can help to make sense of why all of these activities are important. However, as discussed throughout this chapter, the data that has traditionally driven instructional design theories and models is the content, with less than adequate attention to data that may be derived directly from the studying the learner. This chapter has presented a design, which was carried out in an attempt to integrate learner-centred data into a simple teaching package in order to test the idea that phenomenographic studies offer a useful source of information for instructional design decision-making. The next chapter will deal with the evaluation of these materials in order to answer that question more clearly, the current discussion focuses on the experiences of the designer.

Design is partly about confidence in one's ability to realize some kind of end product, be it an architectural drawing or a teaching package. Experience plays an important role in confidence, but from doing this work, my own confidence as a designer was affected not by an additional design experience per se, but because the experience added a new perspective and new tools to my portfolio. In previous design experiences, my interactions with students had been limited to carrying out formative evaluation of prototypes, where I did gain some knowledge of how the materials were being understood. However, the data derived from



those interactions tended to focus on usability issues (quite appropriately for prototypes) and structure, but not in a detailed way on how students tried to make sense of what they were learning. The design improvements that resulted from the prototype evaluation were limited to navigational issues, and occasionally to some inconsistencies in the way that content had been presented.

However, with an orientation towards illuminating students' conceptual understanding, my perspective on the design enterprise has been enhanced. I believe strongly in a systematic approach to design to ensure that decisions are explicitly made, not implicitly taken for granted. And having now designed a teaching package based on phenomenographic data, the following summarizes the reasons that an instructional designer might include the kind of learner-centred study data that formed the basis of the current design in their toolkit.

- The data derived from learner-centred studies is qualitatively different to data derived from experts in a domain.

The materials developed for the Open University course on geology were based on an expert view of the domain. From the analysis of the pilot study, we saw that students demonstrated persistent difficulties in understanding geological mapping despite their use of these materials. The data used in the current design goes some way then in filling the gap between the expert view of the domain and the learner's view of the domain. Two examples include the more precise objectives and simplified and targeted visual representations developed, both based directly on conceptual difficulties revealed by students. The next two chapters present the evaluation of the materials, and will test whether or not this design helps to fill that gap.

- Participating in learner-centred studies can enhance the reflective practices of instructional design practitioners.

This is a more subjective claim. The experience of listening to students as they struggled to explain their understanding of the geological mapping task provided a context and motivation for creating something that could address their struggles. In the role of advocate for the students, I consulted with the course tutors and pondered the meaning of the difficulties revealed in the study. This provided three sets of data, one from the students and one from



the experts, and one from the experts explaining how the students had gone wrong. All this data

created opportunities for developments such as the creation of feedback, and in the creation of the learning activities. This richness of data and experience does not exist in design contexts that source only the expert view. This provides evidence that taking a second-order perspective on the design effort with the intent to come to understand the learners' experience yields different data than data from an expert view. We see then that both kinds of perspectives, the first-order expert view, and the second-order learner view provide complementary data sets on which design decisions can be subsequently made.

- There were additional design elements that have emerged as a result of this attempt to synthesize the results of the phenomenographic study;
  - a) identifying and pre-empting pedagogic errors,
  - b) identifying where confusion between discipline-specific terminology and everyday usage may interfere with acquiring knowledge in a domain, and
  - c) identifying potential difficulties associated with the use of visual representations.

These new design elements provide an additional focus for understanding the nature of difficulties that student's experience and a new set of design specifications for consideration.

- Two kinds of analysis that are complementary will satisfy the requirements for a comprehensive instructional design effort; a) initial expert-based content analysis and b) a specialized content analysis of learners' experience of the concept in order to understand the nature of its contrast with the expert's view, and hence discovering the gap to be addressed in teaching and learning.

### **The Conversational Framework**

The conversational model of teaching and learning developed by Laurillard (1993) provides a reference point for how one should design interaction opportunities between the learner and the teacher/teaching system. The design of the geological mapping materials did not fully instantiate the requirements. However, here I consider the ways in which the model was supported. Laurillard et al. (2000) provide the following outline that I have adapted to describe how the current learning materials followed the framework.

<b>Student/Teacher Activity</b>	<b>Support Required</b>	<b>Design Functionality</b>
teacher presents conceptual knowledge	<i>access to presentational material</i>	<i>Geology topics presented to learner in paper-based material</i>
student expresses partial understanding via comment, question or answer	<i>means to articulate viewpoint</i>	<i>Student answers questions, or marks maps to indicate their understanding</i>
Teacher adapts experiential task to help student experience the concept	<i>choice of activities relevant to tasks</i>	<i>Learning activities are presented in a simple to complex sequence</i>
task sets goal for student	<i>support for generation of task-related plan</i>	<i>Goals are set for each of the learning exercises</i>
student adapts action in the light of conceptual knowledge	<i>support for generation of task-related plan</i>	<i>Feedback on each learning exercise provides an opportunity to reflect and adapt to next exercise</i>
student acts to undertake task	<i>interactive tasks available</i>	<i>Static tasks available</i>
student receives feedback on action	<i>feedback on actions available</i>	<i>Model answers provided for each exercise</i>
student reflects on interaction using conceptual knowledge	<i>motivation to reflect on interaction</i>	<i>Model answers provide explanations upon which the student may reflect</i>
student further adapts action plan + student generates new action to undertake task	<i>opportunity to repeat actions to improve performance on task</i>	<i>* Not provided</i>
student receives feedback on new action	<i>adaptive feedback available</i>	<i>Model answers are provided</i>
student reflects on interaction to develop conceptual knowledge	<i>motivation to develop concepts in the light of experience</i>	<i>Model answers provide explanations upon which the student may reflect</i>
teacher reflects on student interaction to begin new dialogue	<i>alternative presentations available</i>	<i>* Not provided</i>
student articulates understanding of conceptual knowledge	<i>means to articulate conceptions</i>	<i>* Not provided</i>
teacher gives feedback on student's account	<i>feedback on conception</i>	<i>Model answers provide explanations upon which the student may reflect</i>

*Table 6 Summary of Conversational Framework Requirements (Adapted from Laurillard et al (2000) Continued*



In the above account, the \* indicates that this requirement was not met by the geological learning materials. In order to provide adaptation and new exercises, a more dynamic medium is required. However, given a static medium such as paper, it is possible to instantiate a substantial number of requirements of the conversational framework as are evidence in the bold entries above.

## **5.5 Design Model and Guidelines**

The guidelines for design have emerged from the experience of carrying out the research for this thesis. The following 4-stage model and associated guidelines represent what has been developed so far. The intent is to continue to develop the guidelines as subsequent evaluation studies and designs are carried out in the upcoming chapters. In addition to the 4-stage model, an overarching management process has been identified that considers the role of experts and others who may be involved in the design process.

### **Stage One: Expert Analysis**

This stage involves collecting and analyzing a variety of expert-based perspectives about what needs to be taught. This is similar to mainstream instructional design task analysis and content analysis. However, the intent in the interaction with the expert in this case includes the determination of the key concepts that will constitute a learner-centred study in the next stage.

- **Carry out an initial expert-based content analysis.** Generate a model set of conceptions on which the design will be based. Along with the process of articulating the model or expert view, the designer gains insight into the expert's experiences of teaching, of strategies that have been successful or have failed, and establishes a relationship with an expert that will be valuable to the later analysis stages if the development process.
- **Analyze existing student work.** Illuminate the perceptions of the expert about areas in which students might be lacking in knowledge. This process involves reviewing examination papers and helping the expert to articulate the kinds of questions we might ask students that would indicate their understanding or misunderstanding of important concepts.

- **Analyze visual representations to ensure that they reflect accurately the conceptual understandings you want the students to learn.** Visual representations need to communicate the concepts that the learner is trying to understand. Collect explanations from the experts in response to queries about what the representations mean from a conceptual point of view and focus on the salient aspects of the representations.
- **Identify technical terms that may be confused with everyday usage i.e. force in physics).** In consultation with the expert, make a list of all the technical terms in the learning materials you are developing, and discuss how these terms may be confused with everyday usage, for example, force in physics.

### **Stage Two: Learner Analysis**

This stage of the model is concerned with collecting and analyzing data from the learners. It begins with defining tasks that will help reveal the learner's understanding of the key concepts associated with the intended learning materials. It includes the identification and analysis of approaches to learning, interpretation of visual representations and difficulties associated with discipline-specific terminology.

- **Create tasks/problems to study that require an application-level understanding of the material.** Exams do not always provide insight into students' conceptual understanding. The tasks or problems used in phenomenographic studies must go beyond simple facts or definitions, and require students to provide explanations of core or key concepts. The learner needs to articulate either through verbal protocols, or through some kind of artifact (i.e. maps, phase diagrams) that they can explain the conceptual underpinnings of an idea.
- **Carry out a phenomenographic study of a representative sample of learners.** Select a representative sample of students in cooperation with the context expert. The selection can be based on a range of abilities as demonstrated on exam or coursework, or as an option for students to volunteer without influence of an expert. The size of the sample can vary from 5 to 20, depending on the amount of time and resources available.



- **Analyze the transcripts or artifacts and develop categories of description** First, develop a few broad categories that appropriately describe the students' work. Then consult with the content expert to develop the categories. This will usually result in a larger number of more narrowly defined categories. At this point, decide whether the categories you have are sufficient in explaining the difficulties revealed in the study. If not, you may need to carry out a more in-depth analysis by developing architecture of variation that shows the logical structure between the categories and the potential points where barriers exist.
- **Look for evidence of deep and surface approaches to learning.** Look for evidence of deep or surface approaches in the explanations that students provide. Surface approaches will tend to focus on discrete elements of a problem. Deep approaches will tend to focus on integrating elements of a task or problem. Describe the approach and categorize the transcripts.
- **Analyze difficulties with visual representations.** Analyze the role that the visual representation plays in the explanations or problem-solving strategies in which the learner engages. Does the learner understand the purpose of the representation, and how it is to be interpreted?
- **Analyze difficulties with discipline-specific terminology.** Look for evidence that students are confusing terminology within the topic area (such as phase vs. phase diagram) and scientific or technical terms with everyday usage, such as valley vs. syncline.
- **Determine sources of pedagogic errors for existing teaching materials.** Look for three broad categories of pedagogic errors: Sequencing (order of presentation), Representations (the use of visual materials), and Mnemonics (the use of rules for remembering). Determine if any of the strategies used in these categories may cause the learner to engage in surface approaches to learning.

### **Stage Three: Design and Development**

This stage of the model involves the integration of the expert and learner analysis data in order to design and develop the learning materials.

- **Generate objectives based on the categories of description.** Once the transcripts have been analysed and allocated to categories of description, formulate an objective that had as its focus the problems identified for each category. The objectives should be written in such a way that one could clearly see that having been achieved by the student, difficulty described in the category would overcome.
- **Generate assessment items based on the objectives** The design of assessment items follows logically from the development of objectives, and the two should have a coherent relationship, with assessment items becoming the driving force for the development of learning activities in the design process Generate an assessment item that encourages active engagement of the learner with the content part of the learner for each objective.
- **Generate learning activities that will support the opportunity to successfully achieve the assessment items.** Design learning activities to help the learner to interact with the content, and to compare their understanding with the model understanding This will involve a number of other design elements including development of feedback and visual representations. Additional aspects of a learning activity include helping the learner to situate each activity within a larger context. Provide links back to previous activities through summaries or synthesis, and remind the learner of how the current activity relates to the overall goal of the learning package.
- **Develop feedback for students based on the transcripts from the study and expert explanations provided throughout the design process.** Use the student transcripts to establish the kinds of explanations that the learning activities will need to provide in order to overcome particular conceptual difficulties. These explanations can be developed in consultation with the content expert, or constructed based on previous interviews with the content expert regarding the domain. Always provide the model answer and solution that the student can use to self-assess their answers and solution.



- **Sequence the learning activities based on the level of difficulty as represented by the assessment items.** Establish the level of difficulty by considering the concepts students did not easily understand. In most cases, the more difficult concepts will be demonstrated in the transcripts by confusion or inability to articulate any kind of coherent explanation. Further consultation with the content expert may also provide assistance in establishing the relative difficulty levels.
- **Develop strategies for overcoming difficulties with the use of technical terms** Generate comparative explanations of the scientific and everyday usage.
- **Generate visual representations** Where possible, generate dynamic, interactive representations that allow the learner to manipulate them, with the additional support of conceptual explanations. Ensure that examples and explanations that focus the learner on processes of interpretation accompany the representations.

#### **Stage Four: Evaluation**

Evaluation in this model is a quality check of the design so far. This stage will be further extended as the evaluation studies provide additional input to this crucial step in the process.

- **Use the Conversational Framework to ensure the learning interactions are sufficient.** This teaching-learning model provides a way of evaluating how well the design of the learning environment supports the necessary interactions between the learner and the teacher (or teaching system).
- **Evaluate Effectiveness of the Materials.** Carry out a small-scale formative evaluation study to investigate how well the designed materials assist the learner in overcoming the conceptual difficulties identified in the analysis stage.

#### **Managing the Design Process**

This overarching set of activities is intended to focus on the relationship with the expert who provides valuable data and insights into the design process. Early and continued consultation with this person or persons is recommended.

- **Establish a good working relationship with a content expert who can assist in the analysis of student transcripts, and who is sympathetic to the learner perspective.** This is a key factor in the successful integration of the study data in the design process that will have an impact on everything that you do. Initially, the content expert can provide their expertise in the content analysis. The expert then can assist in defining the scope for a study and creating tasks/problems and in analyzing the results.
- **Communicate Results** The communication of results involves developing a format that can help others to understand the significance of what the learners have revealed in the study. In many cases, the audience will be unfamiliar with qualitative research methods, and may regard the use of student transcript excerpts as suspect.

The above guidelines are intended to assist the designer or teacher to formally identify and analyze the difficulties that learner's experience with content in order to improve teaching and learning. As additional design efforts are carried out, the guidelines will be extended and refined.

## **5.6 Conclusion**

Despite earlier criticism of analytical instructional design as a content-orientated approach, the set of activities that define a design enterprise in analytical terms provides a reasonable set of decisions that need to be made. The question is not that one has to decide on objectives or assessment of learning activities, but on what basis are these decisions made. Analytical instructional design models help one to manage a complex process, but are not sufficient for the actual decision-making because they lack a focus on empirical data.

This chapter has given an account of how a designer may use data from a phenomenographic study of students in designing learning materials. A 4-stage design model and guidelines have been generated to provide some structure to the account, and as this thesis progresses, the model will be re-visited and modified as new lessons are learned. Winograd's (1996) definition of design included the idea that 'design is creative', and in the final analysis, even though we may improve learning by collecting and using the right kind of data, the creative aspect will also come into play. The next chapter will describe an evaluation study to



determine if the learning package designed here helped students to learn about geological mapping.

## **Chapter 6 Evaluation of Learners' performance on geology materials**

The previous chapter described the design of the geological mapping learning materials. This chapter describes an evaluation study that will focus on the impact these materials had on learning outcomes for students. The evaluation study also serves as a case for testing the application of qualitative inquiry and analysis in the instructional design process. The process of analyzing the impact of the materials on the learner outcomes provides an opportunity to consider how the results of the evaluation might inform the refinement of the design guidelines presented in Chapter 4. The focus here is to determine whether implications can be drawn from the results of the evaluation that might reflect on whether or not the design elements as instantiated in the learning materials were effective, and could be generalized to support a set of guidelines for future efforts. This chapter will therefore consider how well the design of the learning materials was received by the students, and where improvements to the process might be made based on their responses.

This chapter describes an evaluation study carried out with students who were studying geology in a 2nd level course at the Open University. The data collected included pre- and post-tests and a questionnaire and was analysed along three related aspects; overall pre- and post-test score comparisons, individual test item analysis and concept mastery. The results indicate an overall improvement of 30% from the pre- to the post-test. A second evaluation study will be described in Chapter 7 that focuses in a more detailed way on the qualitative changes in students' work. Therefore, the implications for the results of the current evaluation will be discussed in the context of understanding the limitations of the evaluation design and developing improved processes for the follow-up study that will be detailed in the next chapter.

This chapter will illustrate how the use of the learning materials helped students to understand key concepts through representative samples of students' work with maps. Simple explanations of the content area are provided in order to help the reader gain some insight into the changes learners demonstrate in their work. A more detailed explanation of the various concepts involved in geological mapping can be found in Chapter 4.



## **6.1 Study Design**

The current study was carried out during the residential school week at Durham University where learners were participating in mapping field work as well as laboratory work. In addition to running the study, I participated in the mapping fieldwork with the students. This experience presented two useful reference points. The first was to experience as a learner if and how the authentic field environment could help me to better visualise what I had been learning from the text books and maps. The second reference point was to determine if the learning materials I had developed were relevant to the field experience and vice-versa.

Students' time was tightly scheduled throughout the residential week, so contact time was limited to a one-hour voluntary evening tutorial. The overall methodology for the study was thus constrained, and led to the decision to use pre and post-tests as determinants of whether the learning materials helped students to improve their understanding of interpreting geological maps. Given more time available with students, it would have been preferable to carry out interviews with students in order to be able to compare their stated perceptions following the post-test with the results of the pilot study described in Chapter 4.

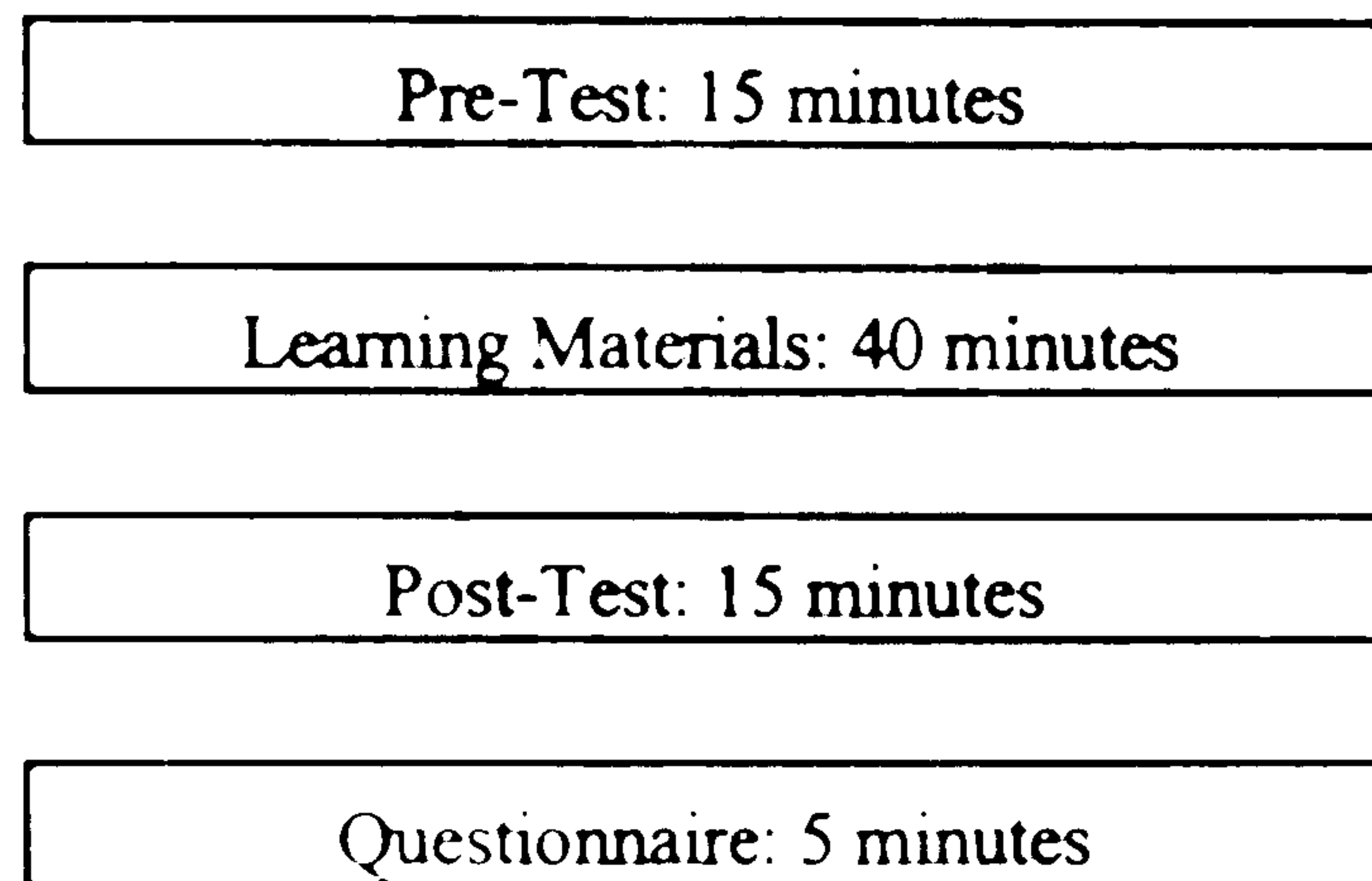
A questionnaire following the post-test was used in order to gain some insight into their perceptions of the experience of using the learning materials. It consisted of a mix of multiple choice and free-form questions that asked students to rate the learning materials according to their difficulty, usefulness, and their perceptions of what it taught them.

Twenty-four Open University students who had been studying a second-level geology course for 7 months participated in this study. At the time of the study, they were involved in a one-week residential school, a large component of which included field work relating to mapping and map interpretation. Twenty-two (22) of the students who participated completed all of the pre and post-tests items, this number therefore represents the sample.

The study consisted of:

- pre and post-tests (Appendix IV)
- learning materials (Appendix III) and,
- questionnaire (Appendix V)

The study took place in a lecture room at Durham University on the evening of the same day that students had participated in a geological mapping field trip in which students were developing maps and cross-sections. Students were informed that the purpose of the study was to determine if the materials were helpful in supporting their learning of interpreting maps. They were informed that the materials had been developed as a result of studying difficulties students in the course had in developing cross-sections. The following is the general procedures and times allocated to the 4 components of the study.



The learning materials consisted of a printed booklet titled "Learning About Folds", described in detail in Chapter 4 (See Appendix III). Following the use of the learning materials students took a post-test to work through individually, and were given the same instructions as for the pre-test. The pre- and post-test questions were identical except that the post-test asked students if they had used any different approach to answering this question on the post-test than on the pre-test. Questionnaires consisted of a mix of multiple choice and free-form for students to rate the learning materials in terms of difficulty, usefulness, what it taught them, their confidence on the post-test, and any differences between the current materials and the Open University course materials on maps. Students were asked to complete a questionnaire following the post-test.



The pre-test and post-test both consisted of 5 questions that are directly related to the objectives and learning activities developed in the design of the teaching package, and as such should be good indicators of the appropriateness of the level of difficulty and a test of how well the teaching package helped the students to gain a better understanding of geological mapping.

### **Rationale and Scoring for pre/post-test items**

The pre and post-test questions can be found in Appendix IV. Students were instructed to complete as much of the pre-test as they could in 15 minutes. Each question was assigned a total of 20 points. The scoring scheme and relationship of the item to the objectives and learning activities outlined in Chapter 5 are provided below.

#### **Question 1 : Label synform and antiform**

This item is related to the following objective from the teaching package:

*Given a visual representation, you will be able to discriminate between antiforms and synforms.*

This item is also the focus for one of the learning activities developed for the teaching package, titled *Comparing Synforms and Antiforms*. Question 1 presents a cross-section view of a synform and antiform and asks the student to label each. This tests whether learners are able to discriminate between these two geological forms. Ten points (50%) assigned to each correct identification.

#### **Question 2: Determine Dip Direction**

This item is related to the following objective from the teaching package requiring students to determine dip directions in order to make a distinction between an antiform and a synform.

*Given a simple geological map, you will be able to identify and explain how V patterns indicate dip direction, and provide clues for interpreting underlying geological structures.*

This item is also related to two of the learning exercises in the package: *Determining Dip Directions* and *Determining Dip Directions from Cross-Sections*. Question 2 presents a map on which students are asked to indicate dip and strike (See Figure 10a). This tests whether learners are able to identify dipping beds. There were 6 central circles for students to indicate the direction of dip. Students needed to have at least 3 correct to receive 10 marks for a 50% score. Students who got all 6 correct received 20 points, or a score of 100%.



**Question 3: Mark and interpret v-patterns**

This item is related to the following objective from the teaching package;

*Given a simple geological map, you will be able to identify and explain how V patterns indicate dip direction, and provide clues for interpreting underlying geological structures.*

This item is covered in the learning exercise titled *Interpreting V's* in which the learner is taught to interpret how v-patterns appear on a plan view where dipping strata are exposed or outcrop at the surface. Question 3 presents a map onto which students are to identify the v-patterns on the intersection of the river (valley) and the dipping strata, and then to indicate the type of fold structures on the map (See Figure 11a.). This tests whether students can identify v-patterns that occur on maps when a geological structure is exposed by a river or valley cutting through a structure, and whether students can apply rules regarding the direction of the v-patterns for determining the type of fold structures (antiform or synform). This question is in 2 parts. If any v-shapes on streams are marked in the correct direction, then they get 10 points (50% mark). If they correctly mark the synform or antiform they receive 5 points (25% for each) or 10 points (50% for both).

**Question 4: Sketch antiform**

This item is related to the following objective from the teaching package;

*Given a simple geological map, you will be able to identify and explain how V patterns indicate dip direction, and provide clues for interpreting underlying geological structures.*

This item is also related to the learning exercise titled *Understanding Continuous Processes* in which the learner is taught how a plan view geological map is altered by the effects of erosion and weathering, with the geological structure remaining intact. Question 4 asks the student to sketch a cross-section depicting an antiform at depth beneath a valley on the topography. This tests whether the student is able to understand that a geological structure at depth can have a form that is different to the topography of the area on the map. They must sketch an antiform to get full 20 points (100 %)

**Question 5: Sketch synform**

Question 5 asks the student to sketch a cross-section depicting a synform at depth beneath a hill on the topography. This tests whether the student is able to understand that a geological structure at depth can have a form that is different to the topography of the area on the map.



They must sketch a synform to get full 20 points (100%). The above question is related to the same objective and learning exercise as Question 4.

### **Summary**

The pre-test was designed to help develop a baseline for each participant in order to draw some implications about learning gains based on the results of the post-test that followed the use of the learning materials. As described above, each of the items were congruent with an objective and learning activity contained within the learning materials. Therefore, the tests appear to be reasonably fair instruments for assessing whether the learner was able to acquire some additional understanding of the material.

## **6.2 Study Results**

Using the scoring scheme described above, the average pre-test score was 57%. The average post-test score was 87%. This represents an average improvement of 30%, with the largest shift being from 10-100% for one student. Eleven students (about half) scored 100% on the post-test and the rest all scored over 50%. Two students did not change scores from the pre to the post-test. Only one student (60% on the pre-test and 50% on the post-test) changed in the negative direction.

The largest improvements were achieved by students who began with the lowest pre-test scores (students 6,14,16,17). This indicates that the materials provided the most learning support for students who arrived at the pre-test with little knowledge of the specific concepts presented, although they had been studying the course for 7 months. Since the learning materials were designed based on the results of studying the difficulties students experienced with mapping concepts, it is an important outcome. Since the only intervening variable between the two tests was the use of the learning materials, this suggests that they were successful in helping students to make improvements in their test performance

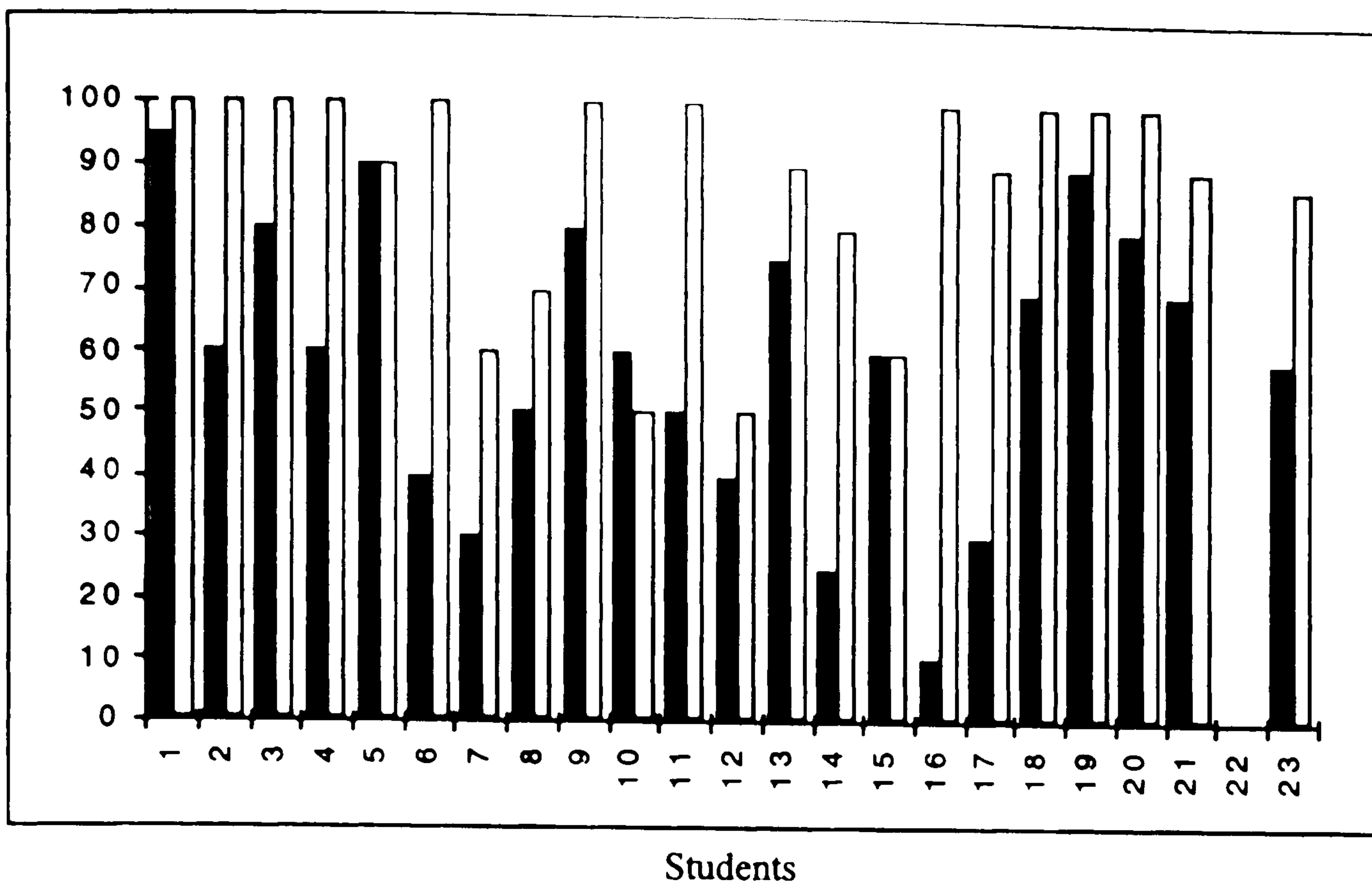


Table 7 Average Pre and Post Test Scores for Durham Study

### Item Analysis

In order to develop a more detailed understanding of the results, the following section describes the analysis of the results for each item on the pre and post-test.

Question 1 (label synform and antiform) of the pre and post-test was a simple discrimination question and nineteen students scored 100% on both the pre and post-test. Only one student got it wrong on both the pre and post-test, and two students who scored zero on the pre-test, scored 100% on the post-test. The overall improvement between pre-and post-test represents only 8%, therefore it appears then that simple visual discrimination between an antiform and synform was understood by most students at this point in the course.

Question 2 (determine dip direction) was easy for many students, with nine students scoring 100% on both the pre and post-tests. However, for those who found it difficult, five students did not attempt the pre-test and scored 100% on the post-test, and two students did not attempt the pre-test and scored 50% on the post-test. One student scored 50% on the post-test following a 100% pre-test. This student also demonstrated a 10% decrease in overall



scores between the pre and post-test, the only participant to decrease overall. The particular errors made in the tests do not reveal a particular problem, and therefore it is most likely that this student represents a unique case. The overall positive change in scores represent 22% from pre- to post-test.

Question 3 (Mark and interpret v-patterns) was the most difficult for students and demonstrated the most variety in the scores for all the test questions. This was probably because not only was the question the most difficult, but there were a number of parts to the question, which made larger variation in scoring more possible. The overall positive change in scores from pre- to post-test was 42%. Only two students had mastered the concept of applying the v-rule for determining the direction of dip on the pre-test. Most students improved significantly from the pre to the post-test, with seven not attempting the pre-test but achieving 100% on the post-test.

Questions 4 and 5 (sketch antiform and synform) were similar but representing inverse situation. The average pre-to post-test score differential was a positive 28%. Average pre-test scores were 59%, demonstrating that prior to using the learning materials, about half of the students were unable to answer these questions correctly.

### **Summary**

The item analysis shows that each of the items except for Question One, provided a good baseline for testing whether or not the learning materials provided support to students in improving their understanding of particular concepts associated with interpreting geological maps by identifying v-patterns, marking and interpreting v-patterns, and sketching antiforms and synforms given a topographic profile. The results of the item analysis shows that the most difficult concept was to interpret the using the v-patterns that occur where a geological structure is exposed by a river or valley.

### **Concept Representation**

In order to represent the results in terms of the concepts students mastered, the data has been placed into concept categories that represented the five main concepts covered on the tests.

Change from Pre-test to Post-test	Identify antiforms and synforms Question 1	Identify dipping strata Question 2	Interpret v-patterns to determine fold type Question3	Distinguish between topographic and geological structures Question 4 Question 5
Scored Same	19	9	5	10
Improved	2	11	16	11
Got Worse		1		

*Table 8: Pre and Post-test Concept Mastery*

The relative changes in concept mastery in order of numbers of students are summarized below:

1. Interpreting v-patterns to determine fold types (16 students)
2. Identifying dipping strata (11 students)
3. Distinguishing between topographic and geological structures (11 students)
4. Identifying antiforms and synforms (2 students)

These changes demonstrate that the materials were most successful in helping students to interpret v-patterns to determine the type of fold represented by the map. The materials also helped students to identify dipping strata and to distinguish between topographic and geological structures. These concepts are inter-related, in that one must first be able to identify dipping strata (as opposed to vertical or horizontal strata) in order to determine whether a fold structure exists. One must also understand that the topography is not isomorphic to the geology, and that a hill can co-exist on the topography where a synform exists at depth and vice-versa.



## Comparisons of student work on pre and post tests

The following section provides a representative sample of student work on the pre and post tests. Questions 2, 3 and 4 are presented with accompanying student work that is representative of the change between the pre and post-tests. Question 5 is not included as it tested the same concept as Question 4, representing inverse situations.

Figure 10a represents a typical problem map used in the Open University 2nd level geology course to teach students about interpreting geological maps in the early stages of their studies. Each of the alphabetically marked areas indicate geological strata. Students are asked to indicate the direction in which these strata dip. This tests whether learners are able to identify dipping beds. The students are asked to put dip indicators into the circles. As described in the scoring scheme for the question, the central 6 circles were of most importance to this task.

Question 2. For the following map, mark the strike and dip directions in the circles provided using the following symbols.

⊕ for horizontal beds  
↘ for dipping beds

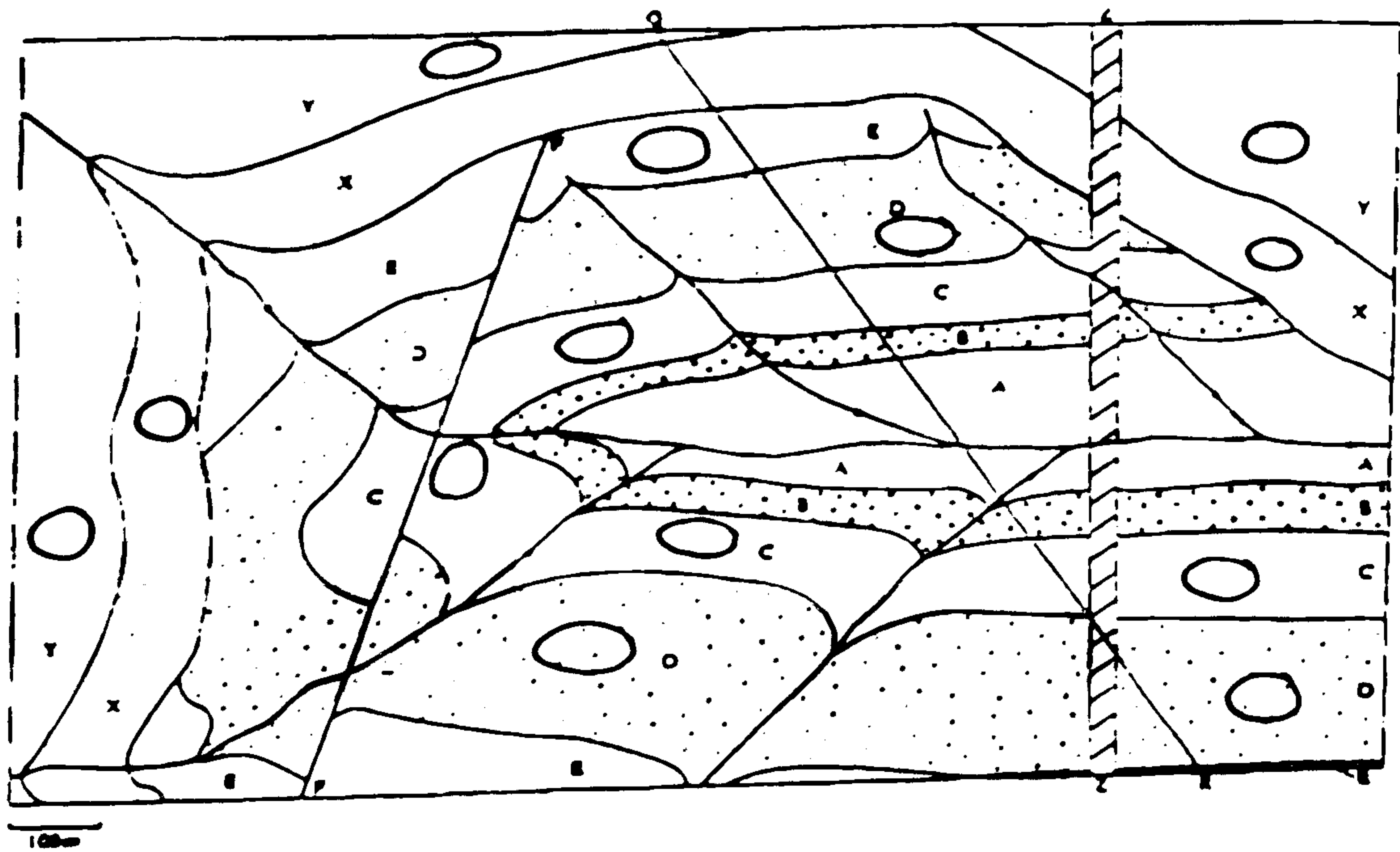


Figure 10a: Question 2 from Pre-test and post-test

Figure 10b is representative of student work on Question 2 on the pre-test. It shows the dip/strike indicators made by the student in the middle of the diagram are incorrect as indicated by the X marks next to the circles. The remaining circles outside of the centre of the diagram are horizontal strata and have been interpreted correctly by the use of a + symbol.

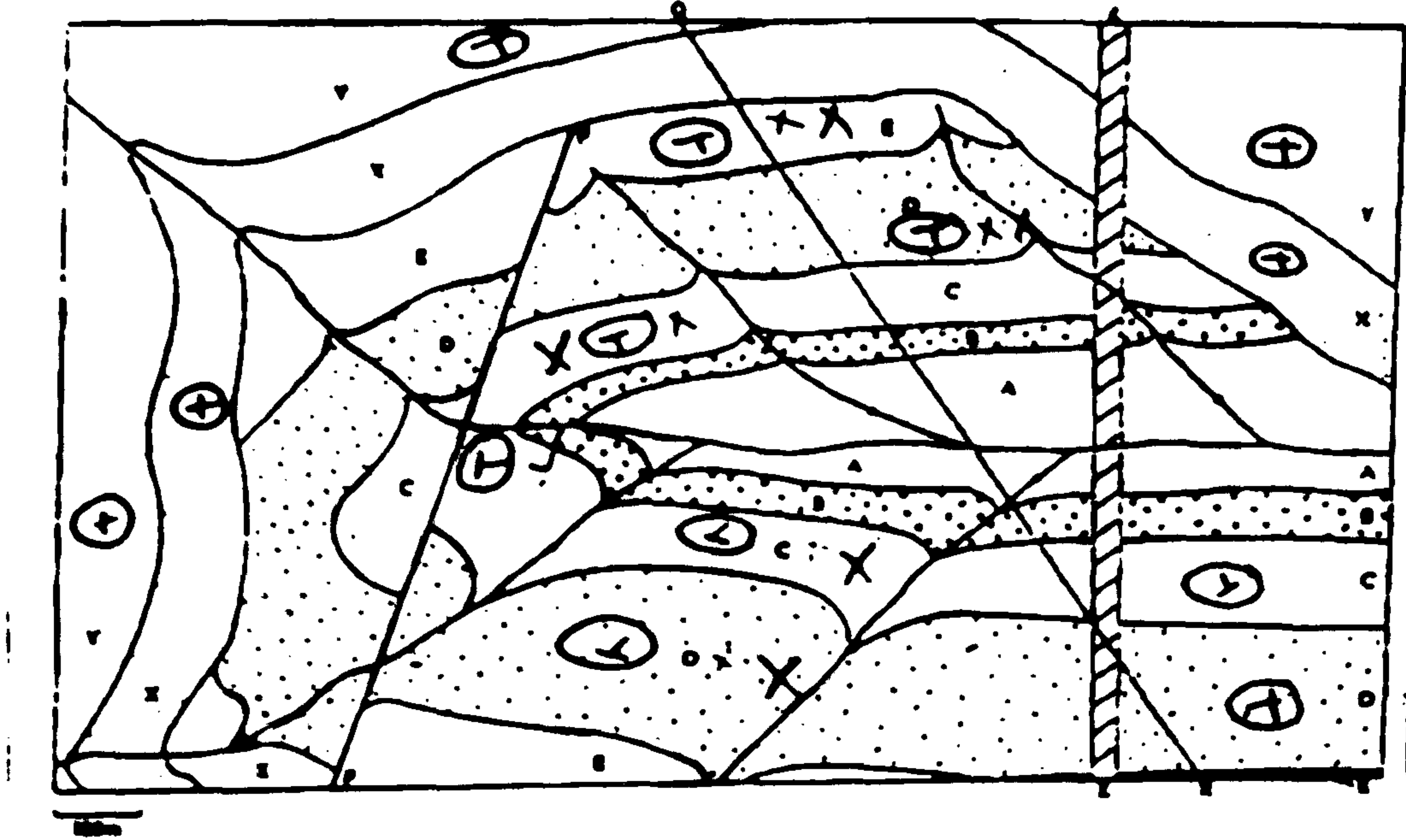
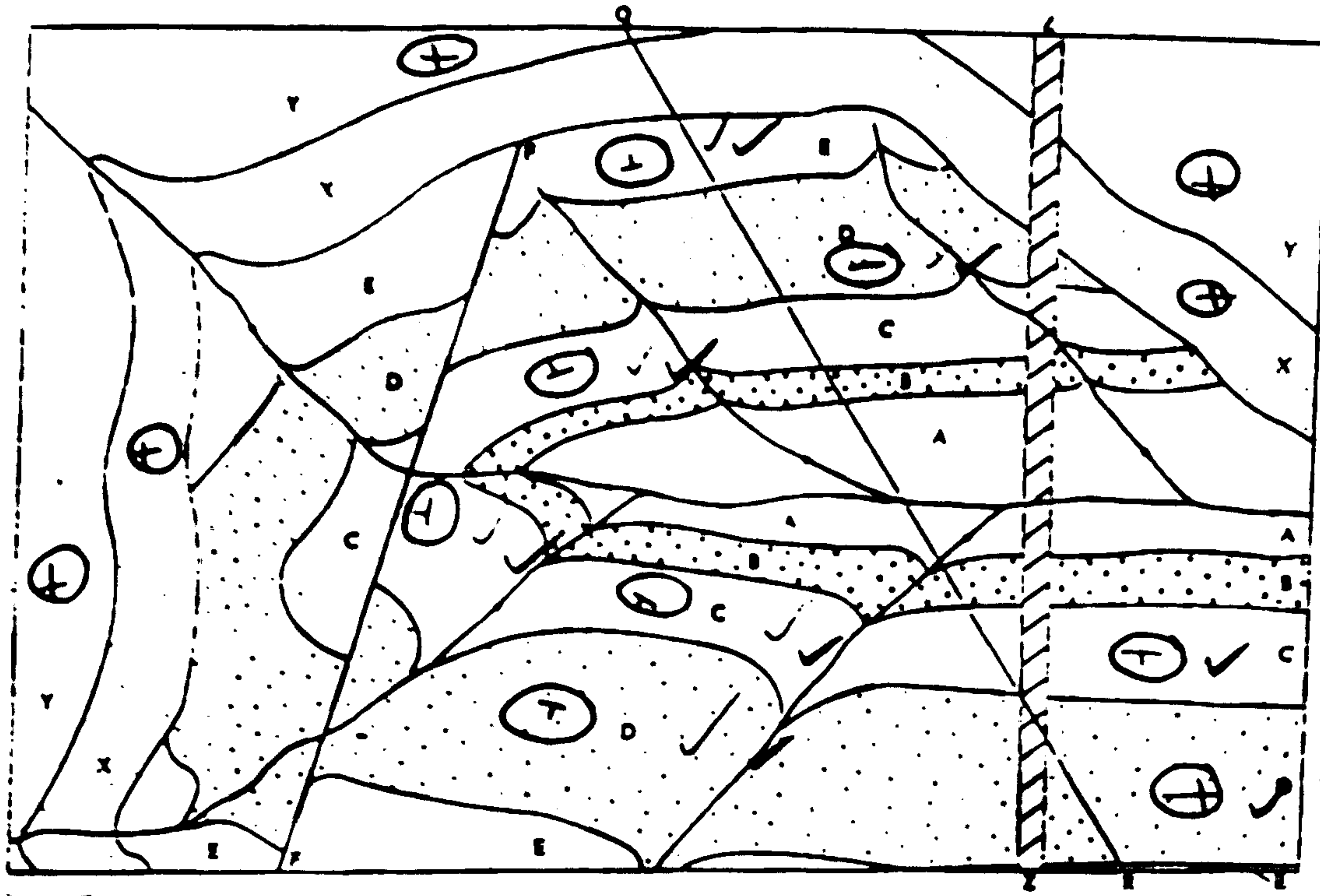


Figure 10b: Student 1 Solution to Question 2 on Pre-test



Figure 10c post-test for Question 2 in which the student has successfully indicated dip indicators in the diagram.



*Figure 10c: Student 1 Solution for Question 2 on Post-test*

For this student, the use of the learning materials has helped them to identify correctly the various dipping beds and the score for this item was 100%.

Question 3 presents a map onto which students are to identify the v-patterns on the intersection of the river (valley) and the dipping strata, and then to indicate the type of fold structures on the map. This tests whether students can identify v-patterns that occur on maps when a geological structure is exposed by a river or valley cutting through a structure, and whether students can apply rules regarding the direction of the v-patterns for determining the type of fold structures (antiform or synform). The previous item analysis showed that question 3 was the most difficult for students in the pre-test, with average pre-test scores being only 36% for this item, with only two students mastering the pre-test and seven students not even attempting the pre-test. Figure 11a represents a map onto which students are to identify the v-patterns on the intersection of the river (valley) and the dipping strata, and then to indicate the type of fold structures on the map. This demonstrates how difficult it is for students to understand how to interpret v-patterns, and their significance to fold

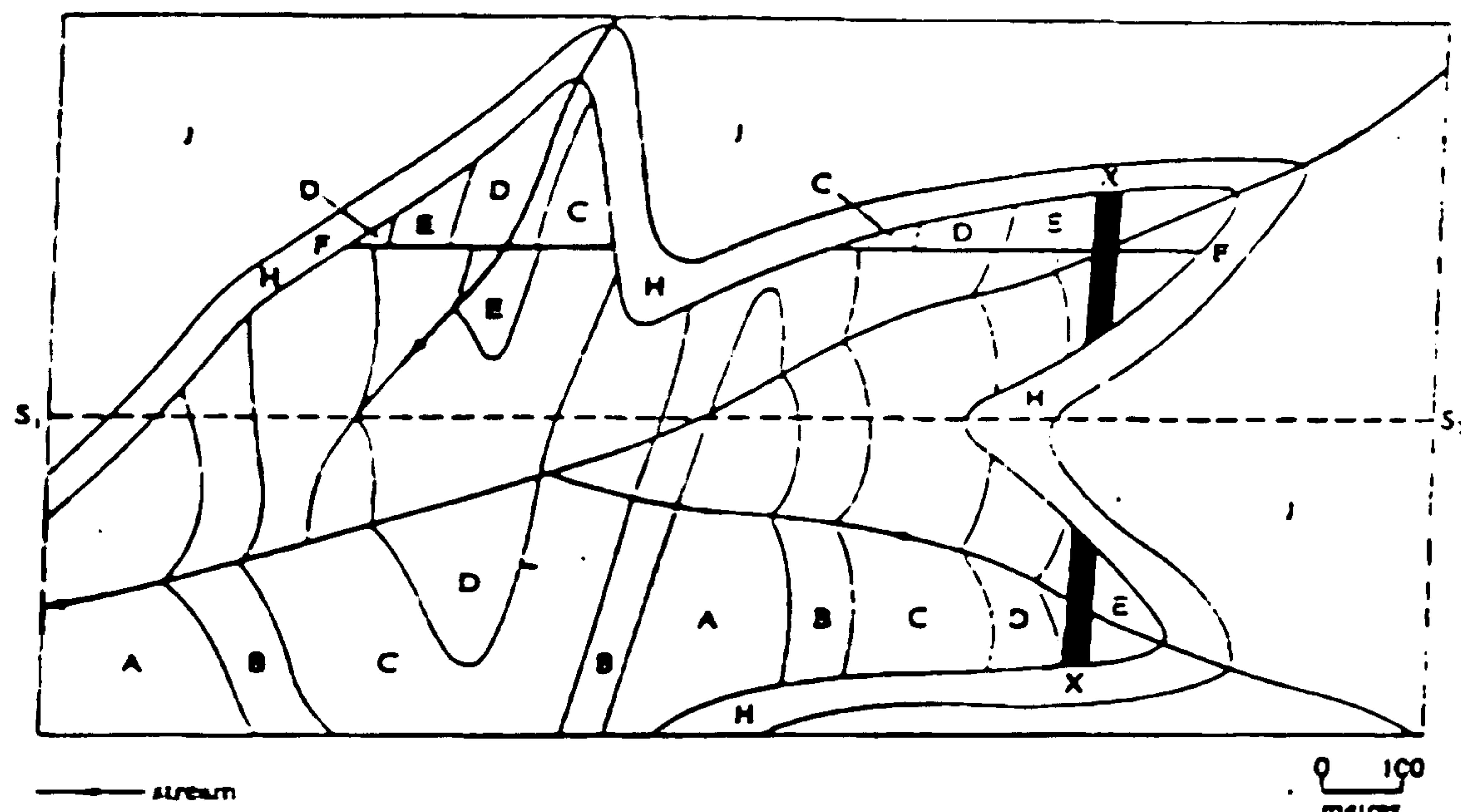
structures. However, the learning materials had a positive impact on students' abilities to carry out this task. Average post-test scores were 78%, representing a positive change of 42%.

**Pre-Test Questions for s236 Study**

**Question 3.** On the map provided, circle any V-shapes on the rivers. Mark any fold axial with the following symbols:

synform — X —

antiform — ◊ —



**Figure 11a: Question 3 on Pre-test and Post-test**



Figure 11b shows the pre test for Question 3 completed by Student #2. This student has indicated the presence of an antiform on the right-hand side of the map, through bed A, with the following symbol :



This is an incorrect interpretation, and scored zero.

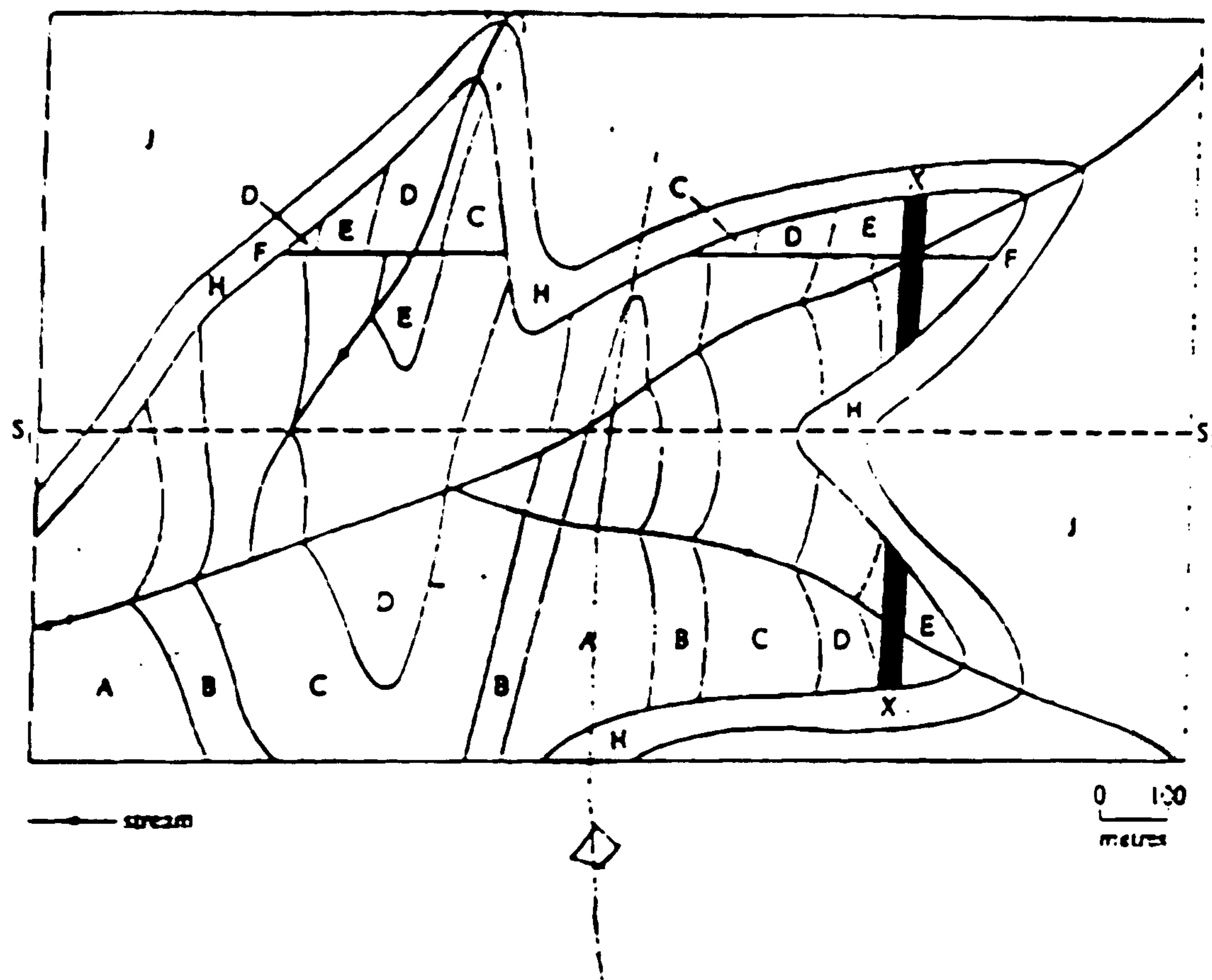


Figure 11b Student 2 Solution to Question 3 on pre-test

In Figure 11c the same student has completed the post-test, indicating both folds correctly through D and A and has added dip directions to the map, a more sophisticated interpretation. The correct labeling of the antiform through D uses the following symbol:



This student has also correctly identified the synform through A using the following symbol;



For this student (Figure 11c), the use of the learning materials has helped to identify correctly dipping beds and to interpret correctly the kind of fold structures on the map and scored 100% on this item.

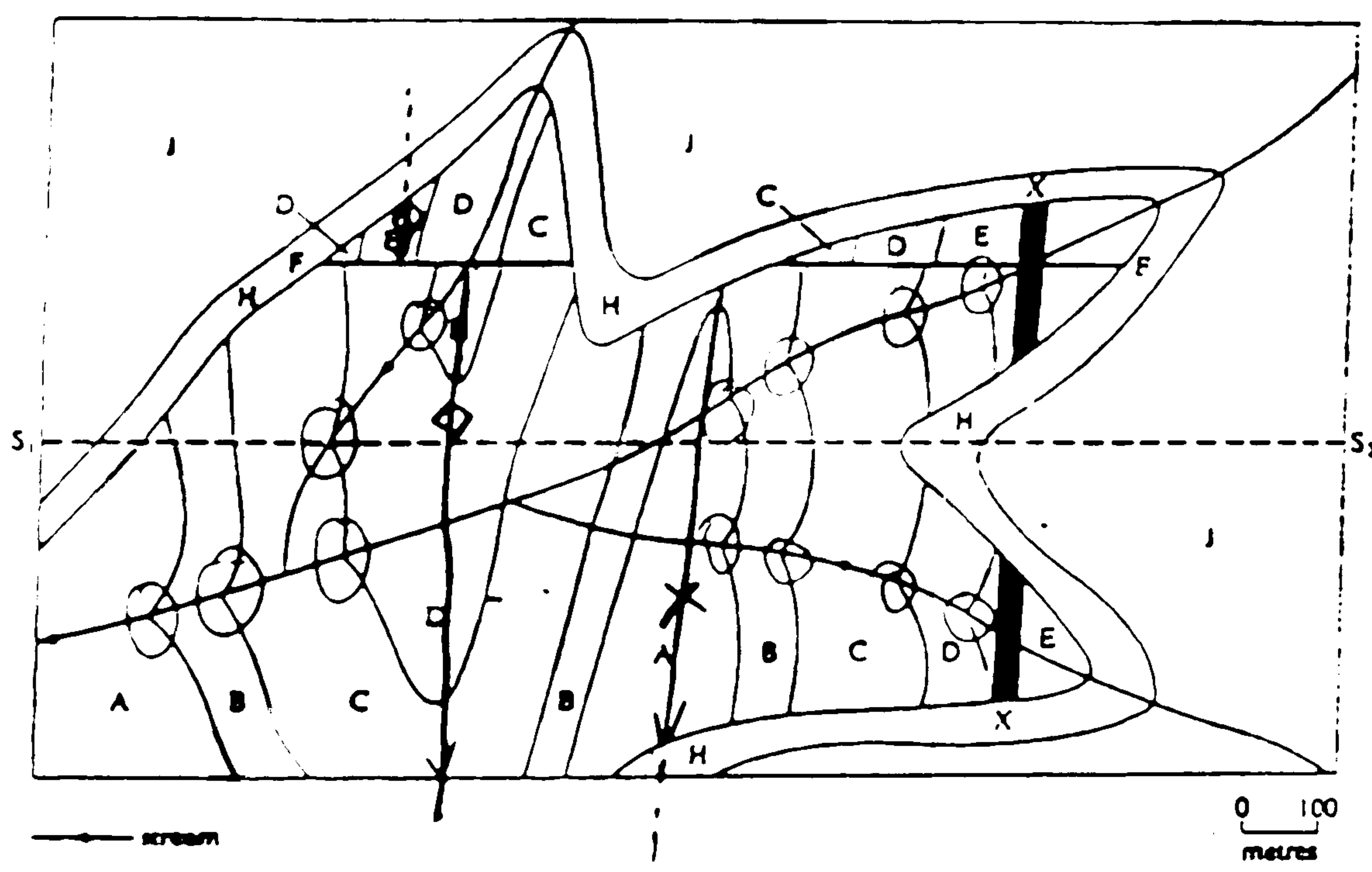


Figure 11c: Student 2 Solution to Question 3 on post-test

Question 4 asks the student to sketch a cross-section depicting an antiform at depth beneath a valley on the topography. This tests whether the student is able to understand that a geological structure at depth can have a form that is different to the topography of the area on the map. The student is being asked to imagine how a geological structure at depth relates to the topographic profile as represented in cross-section.



Pre-Test Questions for s236 Study

Question 4 Using the following topographic profile, draw a sketch cross-section which illustrates an antiform where there is a valley at the fold axis of the antiform on the topographic profile.

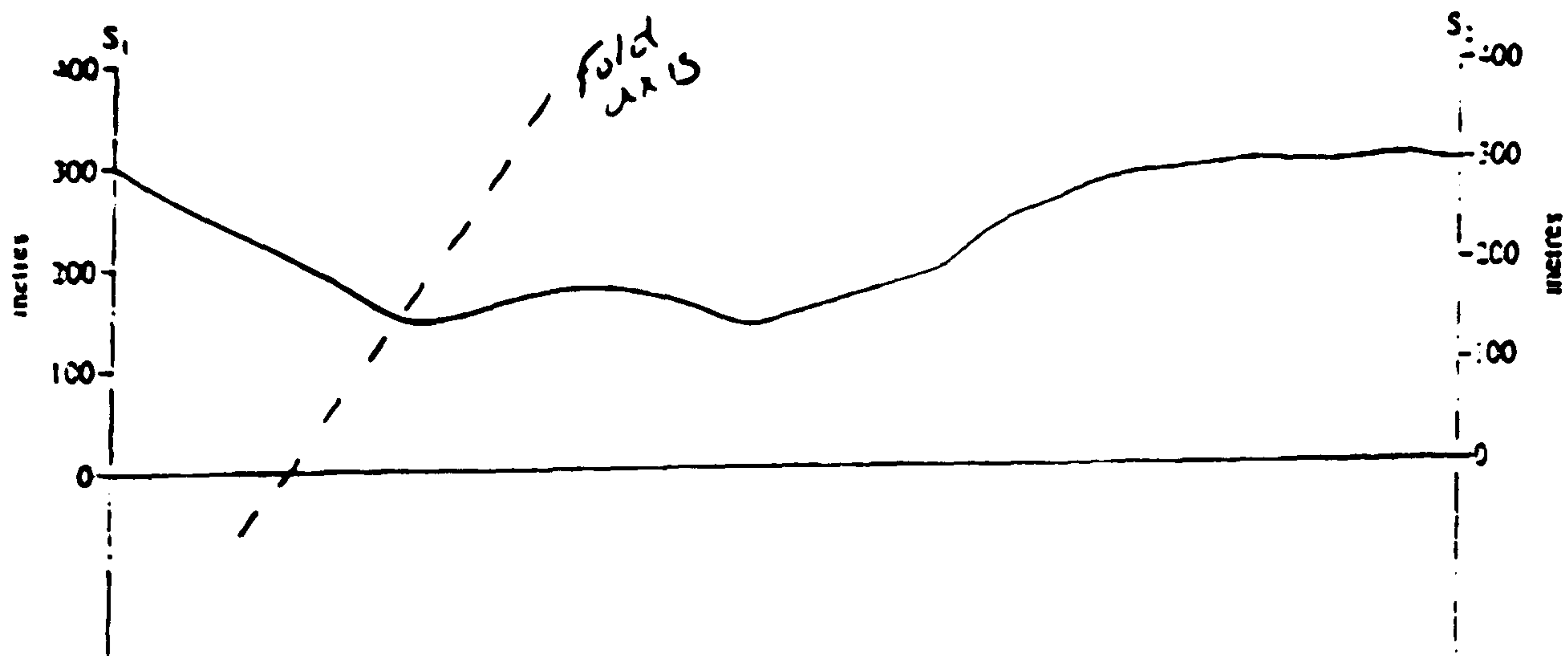


Figure 12a: Question 4 on pre-test and post-test

The following is the post-test for student #3, who did not attempt a pre-test. The post-test is correctly drawn, showing an antiform (fold) existing at depth beneath the topographic profile indicating a valley. The dotted lines above the topographic profile indicate how the antiform might have appeared prior to the effects of erosion on the land surface that have 'cut away' the top of the antiform.

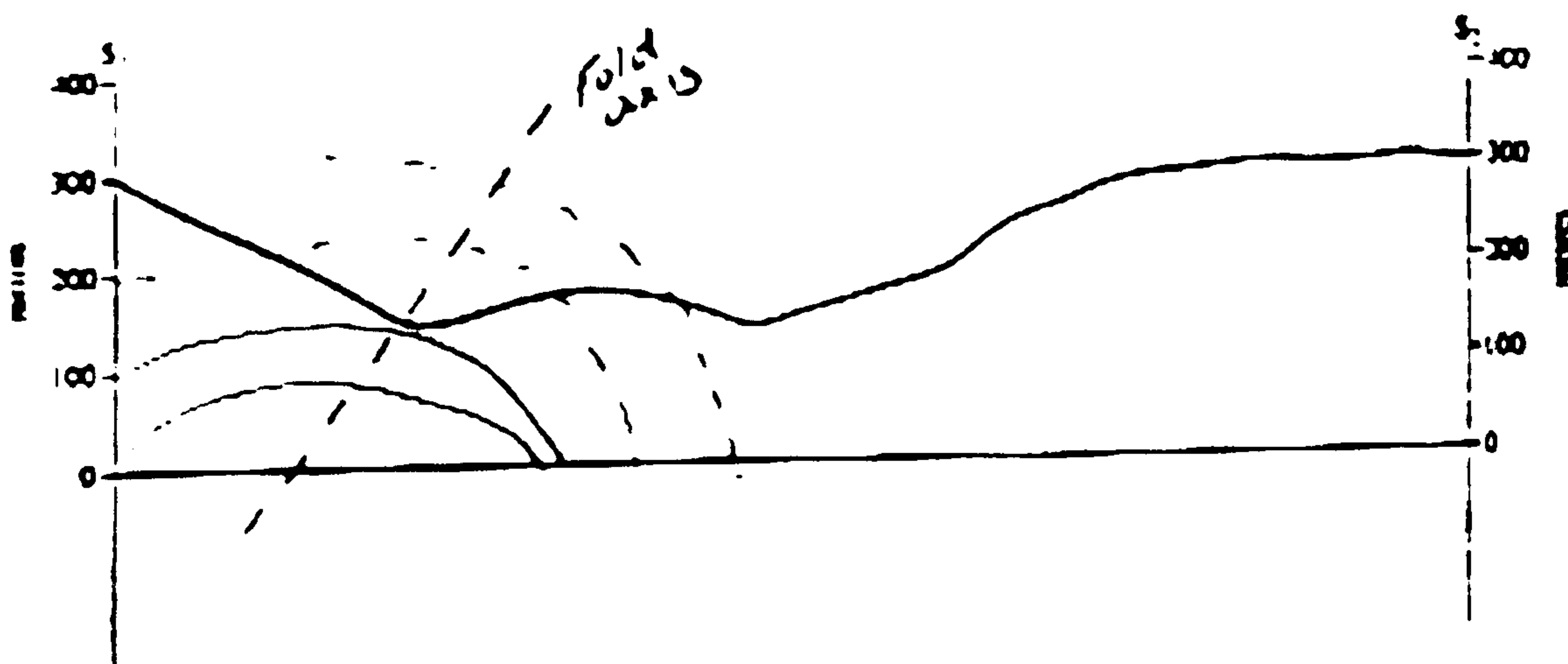


Figure 12b: Student 3 Solution to Question 4 on post-test

If we assume that this student did not complete the pre-test because he lacked knowledge or confidence, we can conclude that the learning materials have helped him to understand the relationship between topographic and geological features, and to understand that changes over time caused by processes such as erosion, have an impact on the topography, not the geological structure. He therefore scored 100% for the post-test item.

### Summary

The above samples from students' work indicates that the learning materials did go some way in helping them to better understand the task of map interpretation, particularly in Question 4 in which there is an important concept to be understood, that topographic (hills, valleys) and geological structures (folds) are different.



There are limitations to the implications one can draw from time-limited pre and post-test studies. The first difficulty is that conducting a short study does not necessarily capture the longer-term learning effect. That is, the design did not include a follow-up study that could provide evidence that the pre to post-test gains were sustained over time. However, in spite of the continual rehearsal of these conceptions over the previous seven months of study, and the recent residential school experience, many students had not mastered them in the way that the learning materials used in this evaluation study did.

There were a number of students who did not attempt some of the items on the pre-test. In particular Question 3 proved to be problematic for students possibly because the form of the question was not in line with other kinds of test items they had experienced in any of their studies. The question asked the students to circle v-patterns in the first instance and then to interpret what these patterns tell them in terms of the geological form. This could have then indicated two things; students could not identify v-patterns or students were confused by the way in which they were asked to perform. Given the kinds of conceptual difficulties demonstrated in the phenomenographic study, I interpreted the non-attempts to mean that students could not identify the patterns. However, this assumption was not tested.

On the post-test, students were asked to comment on anything they did differently to answer the questions following the use of the learning materials. As demonstrated in the following student comments, the mastery scores coincide with the students' experience as they concentrate on the trying to interpret the v-patterns on the maps;

I used the v- directions to indicate dip and the plunge direction by the shape of the outcrop.

Streams v in the direction of the dip

The v-shapes made by the river

I used the river valleys as an indication of the direction of the dip.

In the transcripts above, students indicate that they did attempt to use what they had learned from the materials about v-shapes on maps to apply to the post-test. They are now attending to how the v-patterns that appear on the map can provide clues to interpreting the underlying geology, one of the main goals of the learning material design.

## **Summary**

The results indicate that the learning materials had a positive effect on the students' learning, with a 30% overall increase between pre and post-test scores. In terms of concept mastery, the materials provided most support to learners in understanding how to interpret the types of folds represented on the map by using the appearance of v-patterns on the maps. However, from the following comments made by students it is clear that in the design of the learning materials there is a need to provide additional support;

I know now that beds dip one way for synforms and the other for antiforms but I can't remember which is which

I am not convinced I understand from the teaching booklet the theory behind the dip/v relationship

The above demonstrates that the design of the materials may require a more abstract level of analysis to ensure that the principles and concepts were adequately covered in the explanations and learning exercises.

## **6.3 Questionnaire Data**

In order to capture some of the perceptions of the students about the usefulness of the materials, a questionnaire was administered following the completion of the post-test and the analysis provides some information about how the materials might be improved. This information is also considered in light of potential improvements to the design methodology applied to create the learning materials.

Students were asked to briefly state what they liked about the materials. The majority of students focused on the simplicity of the materials, for example;

It only dealt with one or two points and did not complicate matters with a lot of superfluous information

Helped simplify many points

easy to read explanations and diagrams



However, the simplicity that made the materials easy for students to understand, had a downside for others, for example:

misleading, not encouraging an understanding of the subject, merely encouraging students to cut corners and work out the sort of answer the tutor will think is correct.

the maps were overcomplicated too quickly-the initial example is simple, but the next was far too busy in the visual sense to follow easily

did not cover enough different features

did not understand the questions easily

The first statement seems to indicate that the materials may have encouraged a surface approach to understanding the concepts associated with mapping. The materials were possibly too simplistic for some students. However, for others (as in the 2nd quote above), the visual representation too quickly became complicated.

It appears that the materials were targeted correctly for most students, with the majority (57%) rating the materials at about the right level of difficulty. Only 13% rated the materials as easy, and 9% rated the materials as difficult.

Easy	Somewhat Easy	About Right	Somewhat difficult	Difficult
13%	12%	57%	9%	9%

Students were asked to rate the usefulness of four components of the instructional material. Explanations were rated as most useful, with 62% of students saying they were very useful or moderately useful, followed by feedback (50% very useful), exercises (46% very useful) and diagrams (46% very useful). This indicates that there is a long way to go in improving the design, particularly by increasing the amount of explanations and detail of the feedback. A few students commented that they did not know how the materials related to the course. Perhaps the term usefulness was not the best choice to describe what students experience when reflecting on their learning experience. A better approach may be to list the design elements and ask students to rate them relative to one another. In that way, one might gain a

better picture of which of the elements were perceived as contributing more or less to successful learning. In an analysis of the relationship between the ratings of the elements and the pre and post-test results, I found no consistent correlation between particular ratings and test score improvements.

The next part of the questionnaire asked students what they learned from the materials. For 70% of the students, the materials reinforced things they already knew which is consistent with the placement of the materials in the course as a revision exercise. For 22%, the materials taught them nothing new. 17% of students said the materials caused them to be confused, and only 9% said the materials taught them something new. For this question, students were able to answer in as many categories as they felt applied to them.

Caused confusion	Taught me nothing new	Reinforced what I knew	Taught me something new
17%	22%	70%	9%

The same students who responded that the materials taught them nothing new also said that the materials reinforced things they already knew. It is not surprising that students would perceive that the materials reinforced what they knew, since the material had been covered in the course and they had just finished a laboratory and field trip dealing with similar topics. However, given that there was a 30% average increase from pre to post scores overall, students did at least appear to learn something new from the learning materials. However, there was no clear relationship between pre and post-test scores and the responses on this question.

The confusion caused by the materials may be explained by the unique aspects of the learning activities. The students had never before been asked to identify v-patterns on maps by circling them. They had also never experienced transposing dip directions from a cross-section to a plan view map. However, some students provided additional comments to this question on what the materials had taught them, for example;

differences between antiforms and synforms and the dip direction pertaining to each, also reinforced my knowledge of mapping symbols

the way the streams v in comparison to the dip



the relationship between the direction of the river flow and the dip of slope

Although this study did not seek to directly compare the learning materials with the Open University course materials, I was interested to know if the learners had some perspective on the differences. When asked how the materials compared with the Open University course materials, students said;

More concise on each topic, but not enough covered

More simplistic explanations, less wording to plough through. Concentrated on the main points and explained them clearly

..the brevity that made dip and strike immediate for me

Differently presented, more concise and simple

Students commented on how to improve upon the materials. For example:

Nice presentation, clear to read, but the conceptual assistance is still limited

Not enough detail, will merely lead to confusion when you look at the real examples

I could do with more of these on advanced topics

Based on the above, the materials may be further improved by developing a progression of more difficult examples to ensure that the conceptual understanding generalizes to more complex cases.

### **Summary**

The questionnaire data suggests that over half of the students perceived the learning materials as appropriately targeted, providing easy to understand, simple explanations. Over 70% of the students said that the materials reinforced concepts that they already knew. And for some students, the materials were perceived as too simplistic requiring more complex and detailed coverage of the concepts. I found no conclusive relationship between students' improvement scores and their perceptions of the learning materials.

## **6.4 Summary of Findings**

The results of this study indicate that most students benefited from using the learning materials, and were most helpful to the students who demonstrated the lowest scores on the pre-test. This is consistent with the main tenet of this thesis, that learning materials designed by integrating the difficulties revealed by studying students' difficulties with key concepts will lead to improved learning outcomes. The evidence for this has been presented in the average overall improvement of 30% from pre-to post-test scores. In terms of concepts presented and mastered, the following summarizes the relative changes in concept mastery in order of numbers of students :

1. Interpreting v-patterns to determine fold types (16 students)
2. Identifying dipping strata (11 students)
3. Distinguishing between topographic and geological structures (11 students)
4. Identifying antiforms and synforms (2 students)

Given that the students who participated in this study were enrolled for more than 7 months in a second-level geology course for which the concepts covered in the learning materials had previously been presented, it is evident that the learning materials enabled the target group to gain the kind of understanding they required to be successful in interpreting geological maps.

## **6.5 New Guidelines for Design**

The main purpose of this study was to gain some understanding of how the design of the learning materials had an impact on the learning outcomes. Although the overall results were positive, there were lessons learned about the design methodology. Recall in the previous chapter presented a 4-stage design model according to the following: Expert Analysis Stage, Learner Analysis Stage, Design and Development Stage, and Evaluation. In Chapter 5, the detailed list of guidelines associated with this model were presented and focussed primarily on the first three stages. The last stage, Evaluation, had one guideline entry. The intent is to continue to add new guidelines as lessons are learned from empirical studies.

Recall that the evaluation stage of the model is concerned with reflection on the design itself, and is not a formal formative evaluation with learners. The guidelines provide a focus for



reflection that arises from carrying out the particular kind of design proposed in this thesis, where the inputs are data from both expert and learner experience. By integrating a Learner Analysis of the kind described, the kind of formative evaluation one conducts following the development of a prototype course may involve different activities or foci to a more traditional developmental testing. . The following additional design guidelines are drawn from the results of this study. These new guidelines fit into the last stage of the model; **Evaluation**.

- Once the learning activities have been initially designed, ensure that the main concepts and principles are part of the explanations and feedback provided to learners in order to ensure that the appropriate level of concept abstraction and generality are addressed. This should help to avoid design practice that focuses too much on discrete objectives.
- Analyze each learning activity on the basis of the kind of learning approach that you wish to promote. Look for evidence of strategies that promote surface processing and deep processing.

The integration the above reflective activities should help the designer to step back from a focus on discrete objectives and consider the more general concepts that are to be taught.

## **6.6 Discussion of Evaluation Study Results**

In all pre- and post-test comparison designs there is an issue about providing cues in the form of the pre-test for what the participant should attend to whilst using the learning materials. This may have a positive effect by focussing the learner on the important concepts, it may also focus the learner only to attend to the test. It may be preferable therefore to provide pre- and post-test questions that are not identical, but are representative of the conceptual material so that the post-test is perhaps a better indicator of learning gains.

The results from the Durham study indicated that the learning materials as designed overall had a positive impact on the participants' understanding of interpreting geological maps. However, the pre - and post-tests tests were focused on the separate components of the concepts and the results did not present a picture of the students' overall understanding of interpreting maps. There were two ways in which to improve upon the experience of the

Durham study, either modify the learning materials or change the pre and post-test instruments. Since there was little data on which to base a re-design, new evaluation instruments were developed that were more authentic and general so that students had the opportunity to demonstrate their knowledge of interpreting maps. These instruments also provided the student with an additional communication vehicle, which was to write explanations of their strategies and difficulties in interpreting the maps and drawing cross-sections. This was especially important for interpreting the pre-test results, where many students had difficulty in demonstrating their understanding in any meaningful way using map notation, but were able to express how they were thinking about the interpretation with words.

The results of the pilot study described in Chapter 4 provided a good basis on which to start the design of the learning materials. In the current study students indeed improved their understanding of key concepts associated with geological mapping after using these materials for only an hour. In Chapter 7, a new analysis of the phenomenographic study data is presented that describes the outcome space for the geological mapping task. The results of this analysis is used as the basis for tracking the qualitative changes in learners conceptual understanding in a second evaluation study that uses the new pre and post-test instruments developed as a result of the lessons learned from the current study.



## **Chapter 7                    Evaluation of the Learning Materials in the Context of a Geological Outcome Space**

In Chapter 4 a pilot study of learners experiences with a geological mapping interpretation task was presented that described three categories of difficulties which provided the basis for the design of the geological mapping learning materials described in Chapter 5. In the previous chapter an evaluation study outlined the effectiveness of these learning materials. The conclusion from the evaluation was that the materials provided a reasonably good level of learning support in terms of improving students' understanding of the concepts associated with a geological mapping task. However, I was interested in pursuing even further how the design of learning materials using phenomenographic data can help learners to change from a naïve and ill-formed conception of geological mapping to a more sophisticated and generally well-accepted conception of geological mapping. In order to gain this further insight, it was necessary to carry out new analysis of the pilot study data and develop an outcome space for the categories of description. Because the outcome space is a representation of the relationship between the categories, the new analysis could provide a way of understanding the movement between the categories.

This chapter presents the re-analysis of the pilot study results and includes data from the current evaluation study. A second evaluation of the learning materials within the framework of the new analysis is also presented. Through this process, it is hoped that more precise understanding of improving learning opportunities through design will emerge. The process of coming to understand the research results more deeply is consistent with an action learning and action research approach described in Chapter 2. Recall that action research as defined by Carr and Kemmis (1986) concerns the pursuit of deepening knowledge and understanding within the context of carrying out a research project. In this chapter, the pursuit of deepening knowledge about the geological mapping conceptions is presented through the outcome space of geological mapping in order to further understand the nature of the difficulties learners experience and to further understand how to alleviate difficulties through design strategies and practice.

Following a brief description of the study methodology for the current evaluation study, I will re-cap the results of the phenomenographic study presented in Chapter 4 in order to



demonstrate that the categories of difficulties previously presented are supported by additional data provided by the current evaluation study.

I then will discuss two key aspects of conducting phenomenographic studies; the development of the outcome space, and reliability and validity of results. This discussion includes consideration of the how the notions of approaches to learning, and pedagogic error may contribute to developing and explaining the variation in the categories of description. This discussion will be followed by the description of the outcome space for the geological mapping task that will integrate the results of the current second evaluation study of the learning materials. I also present the outcome space in terms of Marton and Booth's (1997) notion of an architecture of variation.

## **7.1 Study Methodology**

Thirteen Open University students who were enrolled in a second level geology course volunteered to participate in the study. The students were contacted by mail one month before the study and invited to an optional session during a full-day tutorial, a revision tutorial for their upcoming exam. All the participants had been enrolled for 9 months in the course, and had attended a one-week residential school that included field experience in constructing maps and developing cross-sections. The current session took place 2 months after the Durham study described in the previous chapter. None of the students who participated in the current study had participated in the evaluation study described in Chapter 6, nor in the phenomenographic study described in Chapter 4.

The materials used in this study were;

- pre and post-tests (see Appendix VI ),
- the learning materials( (Appendix III) and
- a questionnaire (see Appendix V).

The pre-test and post-test presented a problem map and topographic profile. This map was identical to one used in the earlier study. Chapter 4 contains a more detailed account of the expert interpretation of the map and cross-section. The aim in the current study was to see how well students could interpret general features and concepts.



Students were instructed to do as much as they could with the interpretation of the map within a short period of time and were given the following specific guidance;

- to concentrate on interpreting dip directions and identifying any folds,
- to write down how they determined their interpretation of dip/strike directions and the types of folds they identified and;
- to write down any difficulties they experienced in the task.

The learning materials consisted of a printed booklet titled "Learning About Folds", the same booklet used in the evaluation study described in Chapter 6. Questionnaires consisted of a mix of multiple choice and free-form questions that asked students to rate the learning materials for difficulty, usefulness, what it taught them, their confidence on the post-test, and any differences between these materials and Open University geology course materials on maps.

This study took place in a lecture room at University College London in the early afternoon. Students had participated in a morning tutorial on how to tackle the long questions in the upcoming final exam for the course. The general procedures and times allocated to pre-test, use of materials, post-test and questionnaires were as follows;

Pre-Test: 15 minutes
Learning Materials: 40 minutes
Post-Test: 15 minutes
Questionnaire 5 minutes

Following the pre-test, students were given the learning materials to work through. They were told they could work in pairs if they preferred, discussing the learning materials together. Only 4 people decided to work in pairs, the remainder working on their own through the materials. Students were then given the post-test to work through individually,

and were given the same instructions as for the pre-test, with the additional instruction to write down anything they did differently on the post-test than on the pre-test. Students were asked to complete a questionnaire after the post-test.

The results are described in terms of qualitative changes in (i) the way in which students interpreted the test map, (ii) attempts to draw a cross-section, and (iii) to explain notions of how they went about the task. The test map task was analysed in two parts. The first was an analysis of the markings students made on the maps and any attempts to develop a cross-section on the profile. The second analysis was of the written explanation by the student which accompanied their interpretation of the map. Pre-tests were analysed independently of the post-tests, then both were compared to determine if, and how much, a student demonstrated changes between the pre and post-tests. Six of the students who completed both pre and post-tests demonstrated positive qualitative changes in interpreting the map. Seven of the students demonstrated no change in their interpretations between the pre and post-tests.

In order to support the reliability of the principal researcher's interpretation of the changes from pre - to post-test results, two geology academics from the Open University acted as judges and analysed and commented on 6 pairs of pre and post-test results. Each judge was given a summary of the conceptual difficulties described in the pilot study as background to their interpretation, and 3 blind sets of pre and post-test data to interpret. They were asked to describe the quality of the interpretation for each map and any written explanations students may have included. Judges were instructed to interpret each result independently, to match the pre and post-tests, and then to compare the pre and post for each set. Judges were asked as an optional step if they could comment on how the knowledge of the conceptual difficulties found in the pilot study affected their interpretations of the students' work. The judges' interpretations matched the principal researcher's in every case with respect to the judgement of positive, negative or no change from pre to post-test changes. Thus, the reliability of the interpretation was supported by this evidence. In addition, judges provided interesting commentary on their own perceptions of the difficulties students experience which will be further explored in the Discussion section of this chapter. The judges' interpretations have been integrated in the reporting of the results, and are labeled *J1* or *J2*.



## **7.2 Categories of Difficulties Summary**

This section presents the categories of difficulty that were developed from the prior analysis of the phenomenographic data presented in Chapter 4. Relevant data from the current study results have been added in order to demonstrate that these categories are indeed stable for the intended population of students studied. Recall that the data from the pilot study was interview data, and that the data from the current evaluation study is mainly the completed interpretation of the maps, with some explanatory material provided by the students. A summary of the pre test results and any comments made by the independent judges are provided in the appropriate category of difficulty.

### **Visualization of three-dimensional structures**

Difficulty in visualizing the three-dimensional nature of the maps was evident with a number of students. They were aware that they were supposed to think about how the formations looked as if sliced through, but really struggled with the notion. Many students drew their own interpretations of what they thought the formations might look like, especially where there existed streams on the topography. This, they reasoned, would 'cut in' and reveal more of the structures. The following excerpts demonstrate the difficulties students experienced;

S4: This is my big problem. I can put the marks on the topography, but I can't tell what to do next....I could draw pretty pictures, but 3D is difficult. I was really surprised, because I pride myself on being an artist, but this 3D stuff, that was a real shock.

S2: Is this a syncline?

I: Is it hard for you to visualise what is going on?

S2: I just see the lines on the paper.

I: What might give you an idea about the direction (of the fold)?

S5: The stream beds. Uhhh.....if the....this visualization doesn't come to me very easily, if the slope of the valley is with the dip...I'm just trying to remember the rules.

Current Study Student comments on pre-test: I have difficulty interpreting these maps from a plan view. I can visualise how the fault has thrown the bedding, and how the dyke has intruded. However, I cannot remember how you can tell which way the beds are dipping due to the v-iiing of the streams.

Current Study Student comments on pre-test: In general I have problems trying to visualise the whole map. The cross section I can't picture or begin to see how it would look relative to the map.

Current Study Student A (See Figure 18a ) demonstrates on the pre-test that they are unable to determine the direction of dip on the map and is not even able to identify the existence of a fold structure. This indicates that the student has not been able to visualise that a geological structure exists sub-surface to the 2-dimensional geological map

The above excerpts and evidence from pre-test comments and performance demonstrate that difficulty in visualisation was experienced by students who participated in both the phenomenographic study and the current evaluation study.

### **Present-day topography and geological sub-surface structures**

Folded geological structures are rock strata that are folded as a result of compression by lateral pressure over time. A syncline forms when rock beds are folded down in a trough. An anticline forms when beds are folded in an arch. How the resulting topography 'conforms' with these geological structures is dependent on the rock types, weathering, and erosion. The existence of *present-day* features, such as rivers or streams, do not cause geological sub-structures, but their presence can provide clues to the student who is attempting to interpret a map. A syncline (or folded trough) can co-exist sub-surface to a hill or hills on the topography, and conversely, an anticline can co-exist sub-surface to a valley or valleys on the topography. This may appear paradoxical to a student who may not take into account the effects on formations of different orderings of geological events, such as erosion,



sedimentation, or folding. The following transcript excerpts demonstrate the difficulty students experienced. For example;

S4: The whole area is a syncline, my difficulty is this river, it is going down then climbing up again, we are talking about a river going upstream. Rivers don't do that.

S3: It seems as if the river...here is on high point. It looks as if it coincides with a high point on the profile, which is strange, why should a river be in a high point?

S4: The river is going down, but the rocks aren't.

S4: So now I am beginning to think so we are looking at a valley, so it is a syncline.....the valley is the base of everything.

S6: ....I notice the streams which are useful for the gradients, but I have to be careful there since sometimes I confuse myself with the dip of the rock and the gradients of the ground.

Current Study Data, Student B. The above category of difficulty was also demonstrated in the pre-test of the current study, Student B (See Figure 19b) attempts to construct a cross-section, but interprets the existence of only one fold instead of two, and the structure of the fold seems to match the contours of the topography.

### **Discriminating between anticlines and synclines**

An essential part of reading a geological map is the ability to determine whether a fold is an anticline or a syncline. (Lisle, 1988) The third difficulty demonstrated by students in this study was how to make this distinction. In order to make this interpretation the students must understand the concept of dip and interpreting v-patterns of outcrops. Dip is the slope of a non-horizontal geological surface, and the direction of the dip is the direction in which the surface slopes. The direction of dip can be visualized as the direction which water would flow if poured onto a tilted plane. V-pattern forms on a geological map where a valley or

stream cuts in to the rock beds, exposing the direction of the dip of the formations. The way the outcrop patterns V depends on the dip of the geological surface relative to the topography.

However, as the following excerpts demonstrate, these rules had little meaning to the students, as they were unable to either remember or apply them.

S1: ...I know that the strata are sloping a different way than the strata here but can't tell if it is an anticline or syncline. But I know these shapes here tell me (Note: S1 points to the v's on the map) but I don't know the rules. I know if the river is running that way, then the v's run against the flow, and then on the other side of the structure they flow the other way, but I have forgotten the rule.

S2: It's guess work. I'd say it was an anticline. It dips upstream, doesn't it? So wait, it would be a syncline. It is dipping inwards, upstream:

S5: Normally, you see which is youngest (rock formations), which is oldest, and if one were the oldest then we'd have a u-shaped (syncline), or if it were youngest, we'd have an anti-form...I hope. I can't begin to decide.

S6: I'm still confusing myself about anticline or syncline.....I hadn't taken into account these streams, which are the greatest help.....I'm not confident on this.

In the current study, all of the pretests presented in the later section on pre and post-test comparisons demonstrate that students had difficulty in applying rules about the appearance of v's on the geological maps. (See Section 6.6)

Students are clearly struggling with how to understand the way that one can use the v-patterns to interpret the direction of the dip, something they need to know in order to help determine whether a structure is an anticline or syncline. These rules, then, do not appear to be meaningful as the students have no idea how to interpret or use them in the context of the interpretation task.

## Summary



This review of the previous analysis with additional evidence to support the categories of difficulty from the current study demonstrates that the categories appear to be reasonably stable for this population of learners. The following sections provide a general description of the development of categories of description, or the outcome space, and issues of reliability and validity in relation to phenomenographic study. This will provide a framework for presenting the new analysis of the phenomenographic data in the form of the outcome space for geological mapping. The results of the current evaluation study will then follow in the context of this framework.

### 7.3 The Outcome Space

In phenomenographic analysis, the mapping of possible ways in which a topic of interest is understood is referred to as the outcome space. The mapping of the outcome space is an aggregate analysis of a group of students and is the result of analyzing data derived from student interviews and from task performances and explanations of either retrospective accounts of those tasks, or think-aloud protocols. The researcher looks for common themes in the work of students to develop categories that will describe the different ways in which a group of students conceptualize the topic or problem to be solved. These categories are then supported with student transcripts, or problem-solving schemes. Marton and Booth (1997) describe three criteria for assessing the quality of the categories of description;

*The first criterion is that the individual categories should each stand in clear relation to the phenomenon under investigation so that each category tells us something distinct about a particular way of experiencing the phenomenon. The second is that the categories have to stand in a logical relationship with one another, a relationship that is frequently hierarchical. Finally, the third criteria is that the system must be parsimonious, which is to say that as few categories should be explicated as is feasible and reasonable, for capturing the critical variation in the data.*

(Ibid, Pg. 40)

The main job in carrying out phenomenographic analysis is deciding on the most appropriate focus or point of departure that will illustrate the relations between the different ways in which people conceptualize a phenomenon. This is an iterative process of reading and re-



reading transcripts whilst creating and refining possible categories until a set of categories emerges that fits the above criteria.

### **Reliability and verification**

Reliability and verification of the categories that constitute the outcome space are problematic in that it is not possible to prove that categories are the best possible ones in the same way that one might prove the reliability of a psychology experiment through quantitative statistical analysis. There are of course inherent assumptions in carrying out psychology experiments. However, there is a reasonably well-accepted method for communicating the results in accordance with statistical significance. One then has some confidence that a certain level of rigor has been applied. In the case of phenomenography and for qualitative methods in general, no standards exist for methods of verification or reliability, and this leads to concerns about validity.

Saljö, (1988) addresses two issues related to verifying and testing the reliability of phenomenographic studies. The first is concerned with examining the internal logic of the categories, that is the way in which the categories of conception relate to one another, and provides the following example to illustrate:

*There may be an internal structure to a category system in the sense that what separates conceptions of a phenomenon is what is assumed to be in need of being explained. In the case of force (in physics) the most significant difference lies in whether it is assumed that it is in motion or rest, that is the most suitable point of departure for what one observes. Focusing on rest as the 'natural' state of an object implies a particular conception of force, while focusing on motion implies a different (and Newtonian) conception.*

(ibid., Pg. 45)

If the distinctiveness and relations between the categories can be clearly demonstrated, it is also possible to show that learning occurs when an individual changes his or her conception of a phenomenon and theoretically this change takes place within the structure depicted by the



category system provided. This assumes that the category system that has been derived draws from a representative and sufficiently large sample.

A second way of dealing with the issue of reliability is by using independent judges to determine whether the transcripts that were allocated to the categories of description by the researcher are done consistently, and that the wording of the categories sufficiently communicate their meaning to others (Bowden, 1994). This co-judging is a process of testing whether the categories would be supported by the same data by another person, who is normally a researcher who has some expertise in the field of phenomenography. Although it is unreasonable to expect a perfect agreement, reported studies have found agreement between original categories and the excerpts and the co-judging to be between 80 – 90 percent. (Saljö, 1988)

### **Representing the Outcome Space**

There are various ways in which the outcome space may be represented and communicated. Lybeck et al. (1988) in their work on the mole concept in chemistry developed a detailed collective map of patterns of reasoning which they then used to generate a graphical outcome space of conceptions depicting the relationships between and amongst the categories. Marton and Booth (1997) observe that categories of description as a rule form some kind of hierarchy.

*The hierarchical structure can be defined in terms of increasing complexity, in which the different ways of experiencing the phenomenon in question can be defined as subsets of the component parts and relationships within more inclusive or complex ways of seeing the phenomenon.*

(ibid. Pg. 125)

Booth (1992) developed a series of propositions to describe the different ways in which students understood the intent and related activities of programming represented in figure 13 below.

- **Learning to program as *learning a programming language***, in which focus is on learning the features and the details of one or more programming languages;
- **Learning to program as *learning to write programs in a programming language***, in which focus is on learning to write programs which make use of available techniques and features of the programming language;
- **Learning to program as *learning to solve problems in the form of programs***, in which focus is on learning to produce programs according to the needs of problems;
- **Learning to program as *becoming part of the programming community***, in which focus is on learning to solve problems and write programs in collaboration with, or for, someone else, and thereby participate in the world of programming.

*Figure 13 Four conceptions of learning to program (Adapted from Booth, 1992, Pg. 119)*

The above is one of a number of analyses about the nature of programming that focuses on students' conceptions of what it means to learn to program. The conceptions represent a broadening of perspectives of the purpose of learning to program. It more or less represents progressive levels of sophistication that comes with professional experience and the role one plays in their professional community.



Renstrom (1988) presented an outcome space for conceptions of matter in a study of students between 13 and 16 years of age. The analysis of the interviews resulted in six ways in which students described their understanding of matter and also represents a progression of sophistication in the students' conceptions;

- A. Matter as a homogeneous substance*
- B. Matter as substance units*
- C. Matter as substance units with small atoms*
- D. Matter as aggregate of particles*
- E. Matter as particle units*
- F. Matter as systems of particles (From Renstrom, 1988)*

Beginning with Category A, the students demonstrate a rather undifferentiated view of matter, progressing to B where they begin to conceptualize more specific units, but still undifferentiated, and further progression to particular types of particles (atoms) within units, to Category D, where there is a notion of groups of units. The final conception F demonstrates a more ideal and sophisticated conception of matter where the idea of relationships (systems) between particles and units starts to emerge. This represents a classical phenomenographic outcome space where the analysis of transcripts results in a tidy set of categories that have a clear progressive relationship with one another.

This discussion has illustrated the nature of outcome space hierarchies. As phenomenographic research is still in its infancy, there is potential for discovering more structural arrangements in future. There are two important ideas related to the outcome space that will be explored as a way of understanding the meaning of the categories I have discovered in my analysis and as a way of further understanding the potential for the inclusion of a phenomenographic approach to design. They are approaches to learning and pedagogic error. Each is briefly presented, followed by the description of the outcome space and a discussion of how each of these ideas informs our understanding of the nature of the results.

## **Approaches to learning**

In Chapters 2 and 3, a study by Marton and Saljo (1984) is described that explored what university students learned when asked to read a passage of academic text. They discovered that students applied either a surface or deep approach to the task, depending on how they interpreted the demands of the learning situation. A deep approach was associated with perceiving the task as searching for meaning, and a surface approach was associated with finding out as many facts as possible. This study that went on to describe how the approaches students applied were related to learning outcomes. In general, a deep approach to learning was related to a higher order learning outcome, and a surface approach was related to a lower level outcome. Subsequent studies have generally verified these results (Laurillard,1997; Prosser et.al.(1996).

In an attempt to better understand how these qualitative differences develop, I will present examples from student transcripts that will illustrate the relationship between the outcomes of learning and the approaches to learning that students demonstrated in the current study and from the re-analysis of the phenomenographic study from Chapter 3.

## **Pedagogic Error**

Recall from previous discussions of pedagogic error (Chapter 2, 3,4, and 5) that it refers to teaching practices that may have contributed to the development of conceptual difficulties. As we discussed in Chapter 4, potential sources of pedagogic error may explain the persistence of a surface approach to learning, particularly in relation to the use of visual representations where the learner without specific support attends to more superficial mental representations, based upon domain-general, visuo-spatial characteristics. It is also possible to consider how identifying sources of pedagogic error may help us to understand how the learner may or may not progress between the categories of description in the outcome space. The following factors have been previously identified and discussed in Chapter 4 as possible sources of pedagogic error and will be further analysed and discussed in the context of the results of the current study;



### **Sequencing**

The placement of mapping at the early part of the course. When students have no geological theory to support interpretations, they will make use of their existing knowledge, leading to likely misinterpretations.

### **Representations**

The use of representations without sufficient explanation of their meaning. We have seen that students will supplement inadequate information with their own inventions.

### **Mnemonics**

Use of rules for teaching students to interpret v-patterns on maps. Rules applied without understanding lead to an instrumental or surface approach to learning that does not encourage the student to understand the relationship between the rules.

Consideration of factors in teaching and design that may lead to pedagogic error helps to explain why a student fails to make the appropriate progression between categories within an outcome space. In practice then, we may be better prepared to follow design guidelines that help to avoid these kinds of errors.

### **Summary**

The outcome space is a representation of the relationship between the categories of description that emerge from the analysis of student transcripts and artefacts, and is the main outcome of phenomenographic study. However, this thesis is concerned with the particular application of the results of phenomenographic study to instructional design, and therefore its focus is on how the outcome space can be used as a design tool. Throughout the presentation of the outcome space and subsequently with the results of the evaluation study, reference to both approaches to learning and pedagogic error will be integrated with the discussion.

## **7.4 The Outcome Space for Geological Mapping**

The outcome space for three categories of description is now presented. Each category is accompanied by supporting excerpts from student interviews. The outcome space presented here was developed from the pilot study described in Chapter 4 and drew on data from the current study. In Chapter 4, I presented a list of difficulties revealed in the interviews, but not



a fully developed outcome space. In order to further analyze the transcripts, I followed a fairly typical process reported in the phenomenographic literature (Bowden, 1994) of reading and re-reading the interview transcripts, coming up with a thematic scheme, categorizing the transcripts into one or more of these themes, then revisiting the themes again, until eventually a reasonably coherent set of three categories emerged that were logically related to one another. Following this process, I provided the categories and un-matched transcripts to a third party to see if her categorization matched mine. In 90% of the cases, the same transcripts were placed into the same categories as mine, however, there were minor adjustments and further refinement of the wording of the categories.

The use of pre- and -post tests in the current study intended to locate individuals in the outcome space of possibilities for the purpose of determining if the teaching materials had an impact on the students' understanding of geological map interpretation. It was anticipated that the results of the post test would locate them at a more advanced position than the pre-test. If that is so then the intervening teaching would be considered as the main vehicle in succeeding in moving them from a naive conceptual point in the outcome space to a more sophisticated appropriate one, as teaching should do. However, although the actual categories may be described as stable for a particular group of students, individual student conceptions are not necessarily stable. Therefore attempting to locate individuals within an outcome space and tracking movement within that space must take into account that students are in the process of learning, and assessment at a particular point in time is only a snapshot, not the entire picture.

For the purposes of this thesis, the intent is to find out as much as possible about how design elements may be developed in order to maximise the learning environment, and the best data available is a particular moment in time. Ideally, the kind of tracking of conceptual changes in learners' understanding would be over a course of study.

The three forms of conception are described here as 'geological', 'topographic' and, 'fragmented'. Each is described below with evidence from students' interview excerpts and performance on the pre-tests.



## **Geological conception**

A geological conception can be described as the following;

Geological maps represent a plan view of the distribution of rocks seen at the earth's surface. A geological conception includes the ability to visualise 3 dimensional structures from a plan view, integrates the effect of time-related processes in the interpretation of map data, ( i.e. erosion, and folding) and interprets topographical features, such as valleys, streams, or hills, as interruptions in the continuity of the underlying geological structure .

Students who demonstrate this conception are able to reason competently about the way in which the appearance of stratum in relation to topography can be used to interpret geological structures. Their approach to the task is consistent with the notion of a deep approach to learning in which students are intent on understanding the meaning of the data available from the map. Students demonstrating a geological conception sought evidence that would provide the basis on which they made interpretations.

The following figure (14) is the problem map used in the pilot study and the map used in the pre and post-tests for the current evaluation study. The inclusion of this figure will help identify the references made to particular features of the map in the excerpts that follow.

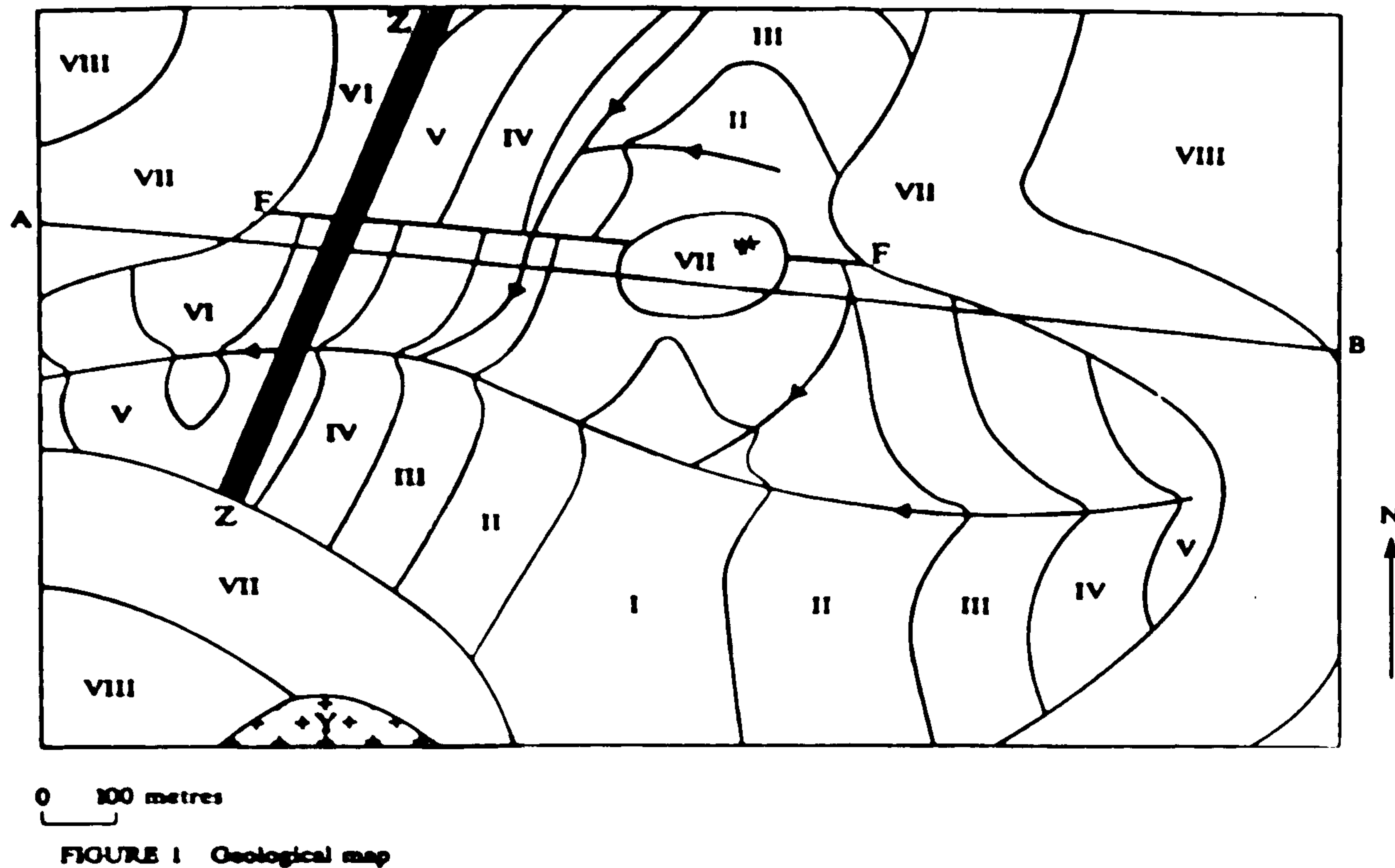


Figure 14 Problem Map used in Phenomenographic Study and Pre and Post-test

The following excerpts from student interviews demonstrate a geological conception and deep approach to learning:

S5: There is another one (unconformity) from the end of the fault F...let's think about this. Oh, I see, I think...looks as though we have a downthrust or an upthrust in the centre that is roughly y-shaped on the east-west plane...the evidence for it is, working around clockwise where 7 meets 7, 5 down to 1 meets 7. (Note: the numbers are the labels for the formations) And on this lower quadrant again there is a 1 to 5 meet that, make it look, it would be an inlier.....

I: What are you looking for now?

S5: Clues, normally this is the stage where I just look at it and start thinking.

S5: That would explain, cut certainly, oh right, it is definitely a dip because it cuts the fault boundary,.....I think confirms the idea that they (formations 7 and 8) are part of the same ridge, and supports the idea of later sedimentation.



The above illustrates a student linking evidence to theory, and interpreting time-related process with the topographic features. The next student tries to do the same, but is wrong about the formations being horizontal. They are in fact part of a dipping, folded structure.

S11: There's the river....so it looks the beds, 12345 are in a sequence that is cut by this dyke and then 7 and 8 are overlaid in a totally different way, aren't they?

I: When you say a sequence, what do you mean?

S11: Well it looks like to me that the beds 1234, are just laying horizontally one on top of the other, and because there aren't any indications (any dip markers) , one can quite safely assume they are horizontal. There's been a movement along this fault F. Then the dyke has come up through after the fault, and 7& 8 have been layered on top.

In the above excerpt we see a student who is attempting to determine the relationship between sequences of geological processes, an attempt to understand the dimension of time in the development of a geological area. Both excerpts show that students were attempting to build some kind of story of how a geological area can be accounted for based on the evidence they seek in the map, consistent with a deep approach to learning as we have seen with S5. However, although the approach is consistent with what we would expect from a student who would then demonstrate higher level learning outcomes, we also see S11 who makes erroneous assumptions about the meaning of the map markings, and could not possibly then go on to make a correct interpretation.

## Topographic conception

A topographical conception can be expressed by the following;

Geological maps show the form of the land surface, i.e. the topography. A topographic conception of maps is characterized by interpreting geological markings on maps as representing contour (elevation) information. Students who demonstrate a topographic conception interpret the boundaries between geological stratum on a plan view map as elevation indicators and therefore interpret geological structures as topographic features, such as hills, and valleys. Students who demonstrate a topographic conception often mis-interpret present-day features as isomorphic with their corresponding geological structures.(i.e. valleys co-exist over a synform, hills co-exist over an antiform).

The topographic conception above is an example of pedagogic error, caused by flaws in the way teaching proceeded to explain and present the geological maps. The maps used in the Open University geology course represent both present-day features (such as valleys, streams, or hills) and boundaries between geological strata, structures usually below the ground surface which have been interpreted by the map-maker, on the same two-dimensional representation. This can be difficult to sort out for students who may not take into account that geological structures form over millions of years, and even though those structures appear altered by topographical features on the surface, the structure at depth remains intact.

Geological folds are structures that result from compression of the beds by lateral pressure over time. The resulting topography 'conforms' with these geological structures, and is dependent on the rock types, weathering, and erosion. The existence of *present-day* features, such as rivers or streams can provide clues to the student who is attempting to interpret a map. A synform (or folded trough) can co-exist sub-surface to a hill or hills on the topography, and conversely, an antiform can co-exist sub-surface to a valley or valleys on the topography. This may appear paradoxical to a student who may not take into account the effects on formations of different orderings of geological events, such as erosion, sedimentation, or folding.



The following excerpts from student transcripts demonstrate a topographic conception of geological mapping:

S7: I have been largely influenced by the general shape of the folds, the marrying up with the topographic profile, and the river flows. I am puzzled by the river arrows.

I: When you did your strat column, you looked at the oldest first, then the youngest?

S7: Yes, because of the way the rivers run it seems to me that....I'm not too sure, okay, the way the rivers run this must be physically the lowest point above sea level on the map, and all these others must be higher. So, that although the confluence here is in this area 3, it must mean between the cross section and this point, the whole things must come down hill.....could be either antiform or synform.....more likely that 2 is the oldest.....there is a fold of some description because of the differences in the thickness of the surfaces of the similar beds, certainly 1 is a lot wider.

From the above excerpt we see that students try to interpret geological structures (folds in this case) in terms of topographic features, i.e. hills.

S3: It seems as if the river, and this little stream here is on a high point, that is what I mean by the,..

I: This river here is on a high point?

S3: It looks as if it coincides with a high point on the profile, which is strange, why should a river be in a high point. I'm sure it's just the slight difference in scale on the profile.....

The above excerpt illustrates that this student is confusing a 'high point' on a geological structure (an antiform which has been interrupted by erosion and later appearance of a river) with the 'high point' on a topographic profile. Topographic contour lines (lines which indicate the elevation of the topography) were not provided on the map.

However, the topographic profile provides the student with similar information, in a cross-section view. This student has confused the boundaries between the different geological stratum and topographic contour lines.

S4: VII must be a high point..a hill. I think judging from the direction of the contour lines.

The following student is expressing that the present-day features should somehow match the geological structures. In this case, the student is reasoning that a river more logically runs through a syncline, because they assume that the form of a geological syncline is synonymous with a present-day valley.

S10: I do find it difficult to visualise a river running through an antiform (that is if the arrow line marks a river)

S4: The river is going down, but the rocks aren't.

S4: So now I am beginning to think so we are looking at a valley, so it is a syncline.....the valley is the base of everything.

As can be seen from these quotes, students tend to interpret the outcrops on the plan view as though they represented contour lines, and they assume that a folded arch (an antiform) in geology is equivalent to a hill.

In a review of a number of studies about the mechanisms by which diagrams and animations are effective in learning Scaife & Rogers (1996) discuss how in domains with highly evolved notations, such as geometry and physics, the diagrams are more than aids in understanding the content, but are essential in acquiring knowledge in that domain. They postulate that in these kinds of domains the diagrams can only "trade on established knowledge to be effective"(ibid. Pg.199). As we have previously discussed, a potential pedagogic error was the placement of the study of maps at the beginning of the course, where students were unlikely to have gained much geological knowledge. As such, they were not in a position to trade on established knowledge.



## **Fragmented conception**

A fragmented conception of maps can be expressed by the following;

Geological maps are lines on paper that show labels and symbols. Students who demonstrate a fragmented conception use common-sense interpretations of the labels on the maps, such as the alphabetical labeling of geological strata, to use as clues to their relative ages. They are not applying geological thinking in the interpretation task.

Students who demonstrated a fragmented conception focussed on discrete elements without integrating the elements into a coherent story, in line with a surface approach to learning. Entwistle (1994, p.17) in discussing two five-year research programs carried out at Lancaster University, reported that "particularly in science, a deep approach depended on having an adequate prior knowledge of the topic involved". One of the factors identified in the previous chapter on design was that the placement of the study of maps in the early part of the course was potentially inappropriate, where the students' limited knowledge of geological processes at that point was a barrier to their ability to interpret geological maps. This may then explain why students were not applying a deep approach.

The following excerpts from student interviews demonstrate a fragmented conception and a surface approach to learning;

S1: There's a river, that's a dyke, then what am I doing next.....I'll mark the zones I suppose.....now the problem is whether it goes over the top, or that way, whether it is an anticline or syncline.

S6: I would look generally to see if there are any features which catch my eye...one is the fault line, the dyke intrusion, I notice the streams.....I can also see an unconformity running around.

S2: I just mark off the different layers and then just transfer them down to the bottom (the profile).

I: I am interested in how you are figuring out what is going on. Are you building up some idea of the history or the events?

S2: No, not really. I mean, I couldn't really answer that kind of question. I would have to draw this about 3 or 4 times to understand that.

The following transcript excerpts are a good example of a student attempting to make some kind of logical sense of the map, unfortunately, becoming more and more muddled as he attempts to understand what he is saying.

S4: Okay, it is obvious we have a diagram here, it's a plan, um, which is two sides of some kind of valley.

I: Can you show me where the valley is then?

S4 My instincts tell me it is there, but it's not because .....(pause) I think we have some kind of anticline, looking straight down on top of it

I: Right

S4: At the bottom of the picture, the first area, then on other side of it, progressively going out on either side equally, you have 3,4,5, um, we haven't got a key

S4: Underneath the line A-B, you've got this area 1, then 2,3,, then the lines indicate we are dropping down, it's not very clever what I'm saying, my memory is gone here. Either side of this one, I would say we are dropping down, if we are going eastwards, we are dropping, dipping eastwards and if we take the head of that one that is going north, then the 2,3,4 to the west....can we stop here?

S4: I'm totally confused.

I: Can you tell me what you're confused about?

S4: Right, what I tell you now is that up there that's a valley, right and what I was saying just now is wrong. The heads from the 1, going above that A-B line, through that circular 7, then 2, then 3. You with me? That is some form of valley.



From the excerpts above we see that the students considered this a mechanical task. These students had great difficulty relating the features on the map to any kind of coherent picture or history of a geological area.

### **Interpreting Dip Directions for Identifying Folded Structures**

The following is a more detailed analysis of the concept of dip within the three forms of conception of geological maps. Dip is the slope of a non-horizontal geological surface, and the direction of the dip is the direction in which the surface slopes. The direction of dip can be visualized as the direction which water would flow if poured onto a tilted plane. V-patterns form on a geological map where a valley or stream cuts in to the geological strata, exposing the direction of the dip of the formations. Interpreting dip direction from the maps used on the Open University course, and using the maps used in this study, could be accomplished without applying a geological conception of maps. However, the confidence of students who demonstrated a geological conception was evident in their map interpretations, particularly for those who were able to develop correct cross-sections. The following provides a summary of the way in which students demonstrated thinking about interpreting dip directions in the context of the three conceptual categories,

#### **Geological conception**

V-patterns forms on a geological map where a valley or stream cuts in to the geological strata, exposing the direction of the dip of the formations. The way the outcrop patterns V depends on the dip of the geological surface relative to the topography.

#### **Topographic Conception**

The direction of the dip of strata is the same as topographic slope. The v-patterns then indicate the direction of the slope of the formation.

#### **Fragmented conception**

The direction of the dip of geological strata changes according to the flow of rivers and streams on geological maps.

The main rule for students to remember about v-patterns on plan view is that where dipping strata are exposed by valleys or rivers, v-shaped patterns point in the direction of the dip. The

rules can be applied without any geological thinking, and thus are not a very good measure of how well a student is interpreting a map geologically. That is, one can apply the rules (if one can remember all the cases) without really understanding the geological significance and get the interpretation right.

The following transcript excerpts demonstrate the difficulties students experienced in applying the rules for interpreting v-patterns on the maps to determine the direction of dip. This excerpt indicates a topographic conception of geological mapping.

I: What might give you an idea about the direction of dip?

S5: The stream beds. Uhhh.....if the....this visualisation doesn't come to me very easily, if the slope of the valley is with the dip...I'm just trying to remember the rules.

The above excerpt also shows a topographic conception in which the student is relating the slope of the valley to the geological concept of dip. He recalls that there are rules that will help him to sort out how to interpret the relationship between what appears on the topography and what that indicates for interpreting the geological structure.

The following excerpts are examples of a fragmented conception of geological mapping in relation to the concept of dip.

S1: ...I know that the strata are sloping a different way than the strata here but can't tell if it is an anticline or syncline. But I know these shapes here tell me but I don't know the rules. I know if the river is running that way, then the v's run against the flow, and then on the other side of the structure they flow the other way, but I have forgotten the rule.

S2: It's guess work. I'd say it was an anticline. It dips upstream, doesn't it? So wait, it would be a syncline. It is dipping inwards, upstream:

The above indicates that the students are applying rules without having attached any meaning to them. The relationship between the v-shapes on the maps and their use in interpreting the dip direction are confused and random precisely because there has been no integration of these rules into 3-dimensional thinking. This is an example of a source of pedagogic error,



as the teaching of the rules either assumed a 3-dimensional thinking, or attempted to substitute rules for 3-dimensional thinking.

### Summary

The outcome space for geological mapping is represented by three categories of description; geological conception, topographic conception and a fragmented conception. A geological conception is associated with an understanding of the map as a three-dimensional representation of the relationship between present-day topography, geological structure, and continuous (such as erosion and folding) and discrete time-related processes (such as volcanic intrusions). A topographic conception is associated with understanding the map as a two-dimensional representation of the form of the land surface, and interpreting the indications of non-horizontal forms as elevation information. A fragmented conception is really a mechanical view of map interpretation, where features and markings are visually identified but have no meaning in terms of a coherent story.

We have also considered the part that pedagogic error may contribute in the design and presentation of materials in understanding the development of surface approaches and to misunderstanding of visual representations.

We have clear evidence of the use of the surface approach to learning for students who demonstrate a fragmented conception where they consider only discrete features and do not relate these features within the context of understanding a map. There is some evidence (from one student in the pilot study) that a deep approach to learning is associated with a geological conception, where we saw the learner seeking evidence to support a theory about how a geological area was formed. The relationship between approaches to learning and the topographic conception is less clear. We saw one student who demonstrated a topographic conception who also applied a deep learning approach, but without success because the basis on which he sought evidence was erroneous. This may point to a difficulty referred to earlier in trying to locate individuals within a particular category at a point in time, as learning is progressing. Another interpretation of this phenomenon is that learning approaches are insufficient to achieving higher level learning outcomes. In the case of geological mapping, we may be dealing with what Laurillard (1993) refers to as 'building on sand'.

We now present an alternative view of the outcome space that provides an additional analysis tool for interpreting the results of the evaluation study. The architecture of variation will represent the path of learning and in doing so, help us to situate the pre- and post-test results.

## **7.5 Architectures of Variation**

Marton and Booth (1997) provide an extensive discussion of how one might develop learning situations around the variations in the way in which learners experience phenomenon. These architectures of variation can be described as the logical structure between and within the components of the outcome space.

We saw an example earlier of an outcome space that that described four categories of conceptions for what students considered to be learning to program (Booth,1992);

- 1. learning a programming language,*
- 2. learning to write programs in a programming language,*
- 3. learning to solve problems in the form of programs, and*
- 4. becoming part of the programming community.*

(ibid, Pg.125)

These four conceptions form a hierarchy that assumes the lower levels of the hierarchy are included in the higher levels. For example, a student who demonstrates a level 2 conception includes a level 1 conception, and one who demonstrates a level 4 conception includes the lower levels. However, this is not a clear progressive hierarchy in terms of moving from a low level of sophistication to a higher level of sophistication as we have seen in the example of conceptions of matter.

An example of a progressive hierarchy can be found in Renstrom (1990) in which an outcome space for conceptions of matter in a study of students between 13 and 16 years of age. The analysis of the interviews resulted in six ways in which students described their understanding of matter and represents a progression of accuracy and sophistication in the students' conceptions; The following figure is the same outcome space as described earlier in



the discussion of the outcome space for matter but interpreted as an architecture of variation where the authors have identified potential paths for development and potential obstacles.

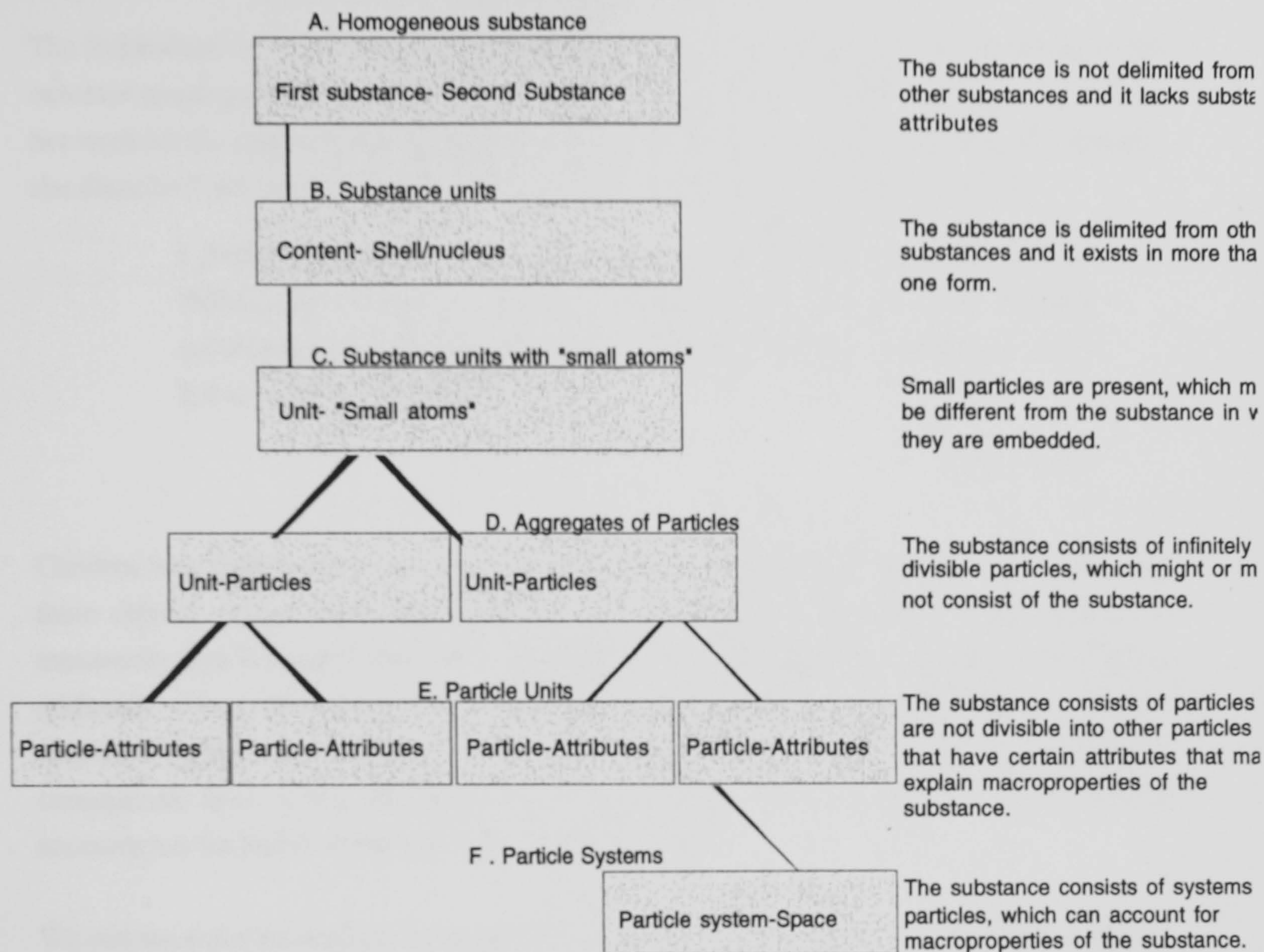


Figure 15 The architecture of variation for matter. (Adapted from Marton and Booth, 1997, Pg.79)

The above is further described by Marton and Booth (ibid.) as an example of an outcome space that has been analyzed on the basis of the awareness of the relationship between the constituents of matter. One progresses from an undifferentiated focus on only the substance itself through to the understanding that different particles exist within a substance that have their own properties. The potential obstacles here are between level D and E and level E and F, where the student needs to consider a number of particle units in order to progress



eventually to the conception of particle systems. This provides an opportunity for teaching intervention in order to assist the student along the progressive path.

The architecture of variation for interpreting geological mapping does not fit into either of the outcome space types described above. It is more similar to the findings of (Neuman,1987) in her work on the origin of arithmetic skills. As part of her studies of seven-year-old children, she described two main conceptual categories, Counting and Structuring. She says;

*I found a cross-road ....from this cross-road one 'main road' and one 'blind alley' emanated....the 'main road' leading to the ten basic concepts (of arithmetic) while the 'blind alley' was the Counting conception, which led to mathematical difficulties."*

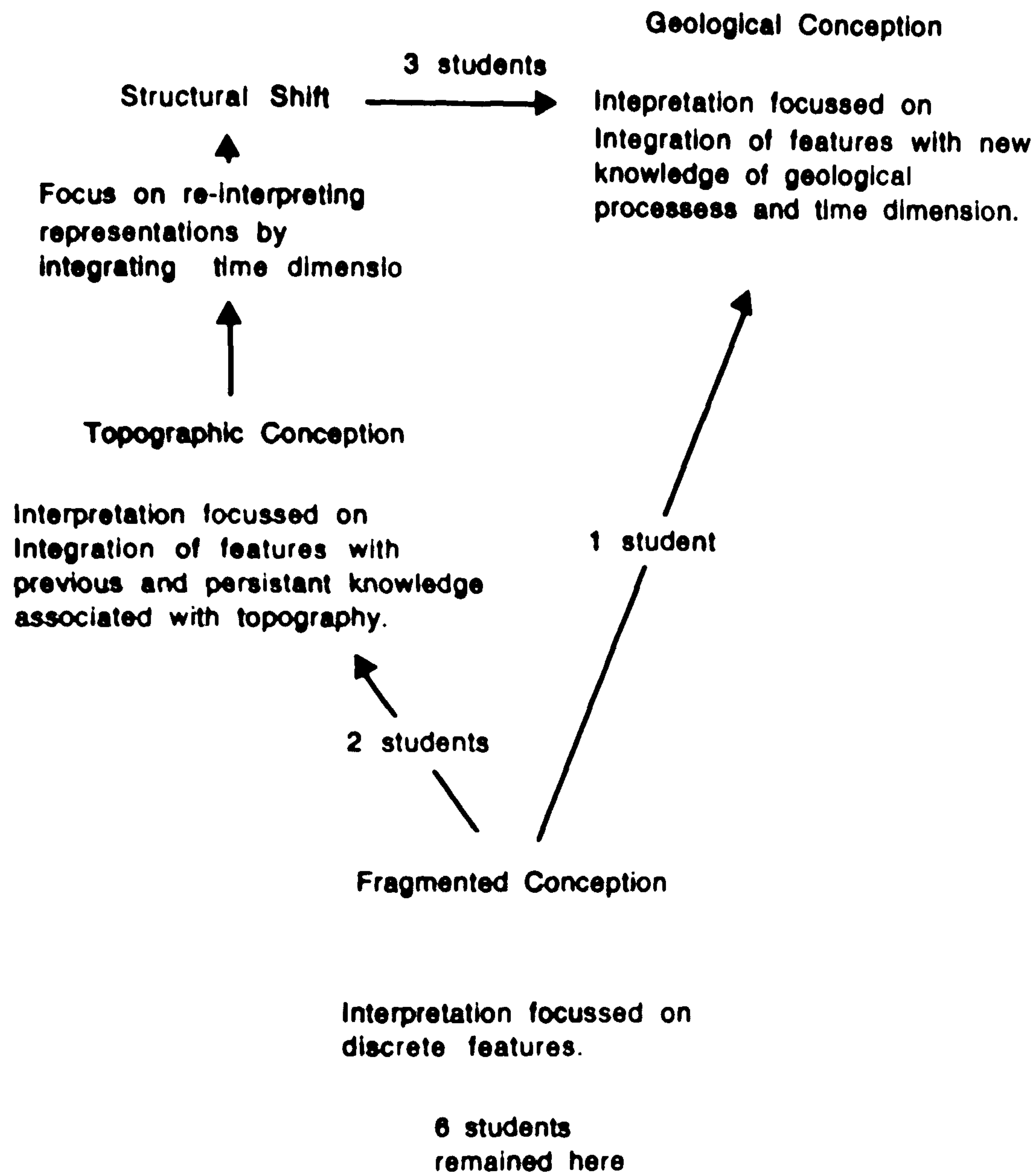
(Ibid., p94)

Children who demonstrate a counting conception consider numerals as objects. We can count these objects, we can order these objects, but the objects have none of the properties of numerosity that is needed in order to manipulate and understand the structure and rules of arithmetic. Neuman contends that the counting conception can never lead to abstract numerical operations, hence it is a blind alley. She further talks about the early numerical conceptions from which the problematic "counting" conception began. More detailed accounts can be found of this research in Neuman,1987.

We can see a similar structure emerge in the geology outcome space. The following figure is an architecture of variation that represents the two main paths students appear to take leading towards two conceptions of geological mapping; a main road to the Geological conception through a Topographic conception and a kind of blind alley for most of the students who begin with a Fragmented Conception and remain there. We see from the figure that students make a structural shift in order to move from a topographic conception, where they first make interpretations of the signs to discern the structures, but then integrate the dimension of time in order to demonstrate a full geological conception. The numbers of students who made the shifts are represented on the diagram, save one who maintained a topographic conception from pre to post-test.



In this architecture there is no inclusion of lower categories in more sophisticated ones, as the students who do manage to move from a fragmented conception to either a topographic conception or a geological must abandon the notion of the map as a set of discrete elements. Students who move from a topographic conception to a geological conception must take on board the new terminology associated with geology. It is not necessary for learners to acquire a topographic conception in order to then move on to a geological conception. In fact, the topographic conception is likely the result of pedagogic error factors as discussed earlier, specifically the wrong sequencing of mapping in the course, and the lack of support for understanding the mapping representations.



*Figure 16 Architecture of Variation for Geological Mapping*

One of the interesting aspects of this architecture is in trying to understand the learning process in terms of Marton and Booth's (1997) notions of discernment and variation, in which they describe how learning is about the ability to discern the critical aspects of a situation or a phenomenon. In Chapter 3 we related some of the studies in expertise to these ideas about learning and saw that the progression from novice to expert was one of developing the ability to more quickly and more effectively discern the correct patterns in a problem set. Glaser and Chi (1988) also pointed out that whereas novices tended to take little



time in analyzing a situation before applying a solution, experts spent more time at the beginning of problem-solving. This intermediate process has been labelled as integration.

The process of integration then becomes a crucial point in the path of learning, where the progression from one conception to another occurs. This may be understood by the notions of learning approach and pedagogic error. When students apply a deep or interpretive approach, they view the interpretation of discrete features of geological mapping as supporting a hypothesis. They are integrating these features into some kind of geological model that is being developed as they learn. In this sense then, the process of integration depends on teaching that supports the learner in developing a mental model of a system into which new information may be integrated. Conversely, students who applied a surface approach had little basis for integration. For them the process of interpretation was one of identifying discrete elements, but not building a model or hypothesis on which to then hang evidence.

## **7.6 Results of the Evaluation Study**

The process of understanding the outcome space in the context of an architecture of variation then can assist us in the task of determining where students require particular support. We now look at the results of the study in the context of the movement of students between the categories of description. Each pre and post test map was analysed for each student to determine which category best described the students' interpretation. This process involved searching for evidence that the attempts students made were indicative of the three different categories. The results are summarized below;

- 6 of the students who began with a fragmented conception continued to demonstrate this conception on the post-test.
- 2 students moved from a fragmented conception to a topographic conception
- 3 students moved from a topographic conception to a geological conception
- 1 student maintained a topographic conception from the pre to post-test, and
- 1 student moved from a fragmented conception to a geological conception

Students were using the teaching package for only an hour, it is therefore surprising that there was the amount of movement described here. In a summary of 5 studies on conceptual change, West and Pines (1985) conclude that;

*... learners' existing conceptions are very resistant to change... despite extensive instruction and acceptable (even outstanding) performances on school examinations, many students cling tenaciously to their naïve conceptions.*

(ibid. Pg.2)

Champagne et.al.(1985) argue that pre-instructional conceptions derived from experience are more resilient than are conceptions in other science areas. In order to gain some insight into the experiences that learners demonstrated on the pre- and post-tests that might illuminate our understanding of these conceptions, the following section will illustrate the changes that took place by illustration of the worked maps.

### **Pre- and Post-test Comparisons**

In order to further illustrate the changes in students' abilities to interpret the problem map and to construct cross-sections from those maps, this section presents the pre-and post-test maps and cross-sections from the work of two students. In one case, as was common for this group, the student did not attempt to develop a cross-section on the pre-test.

Figures 17a and 17b are the solutions to the problem map used in both the pre and post test. The problem map (unsolved) can be seen in Figure 14. It is also the same map used in the phenomenographic study described in Chapter 4. For a detailed description of the markings and interpretation, refer back to Chapter 4.



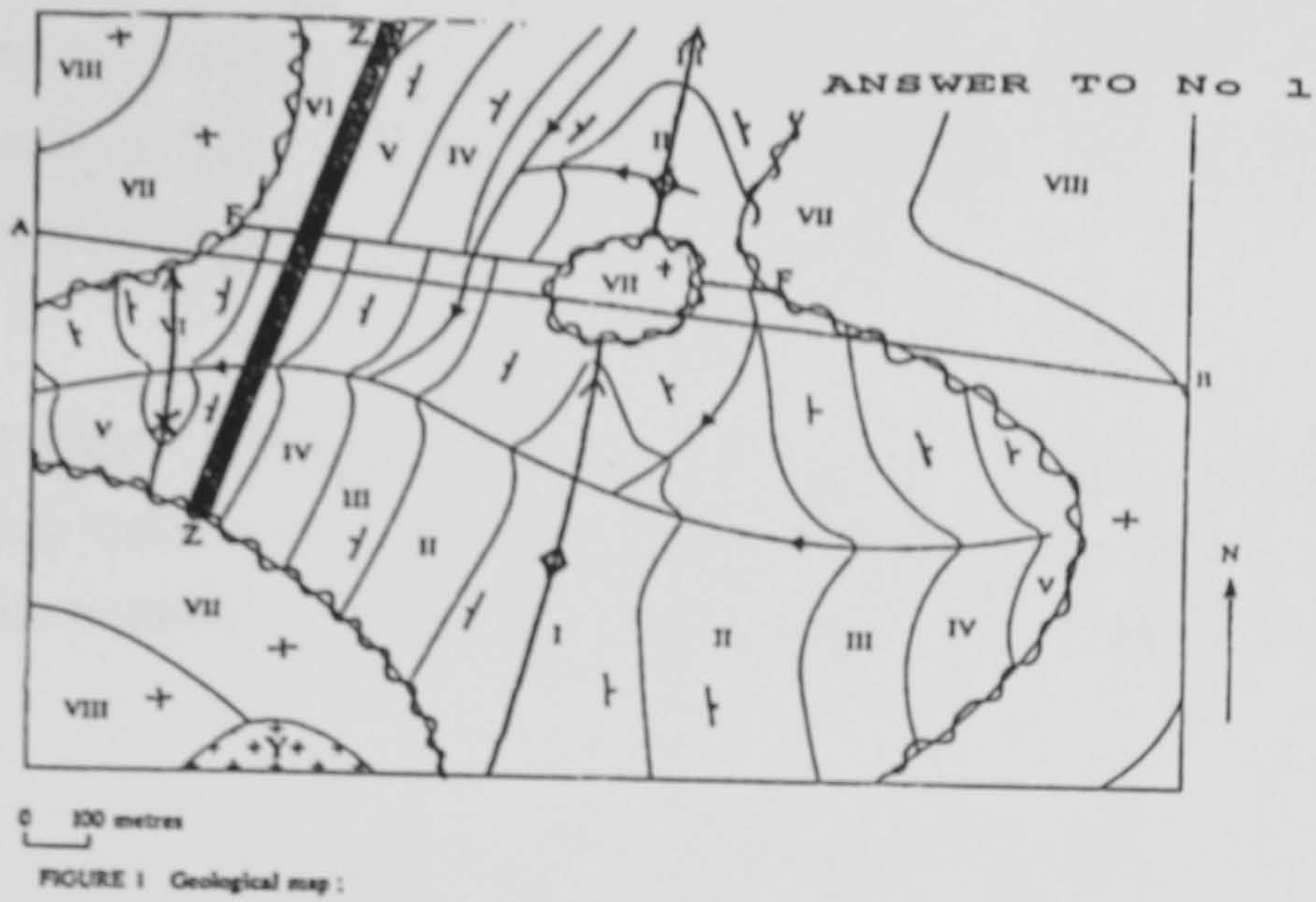


Figure 17a Solution to Problem Map for Pre and Post-test

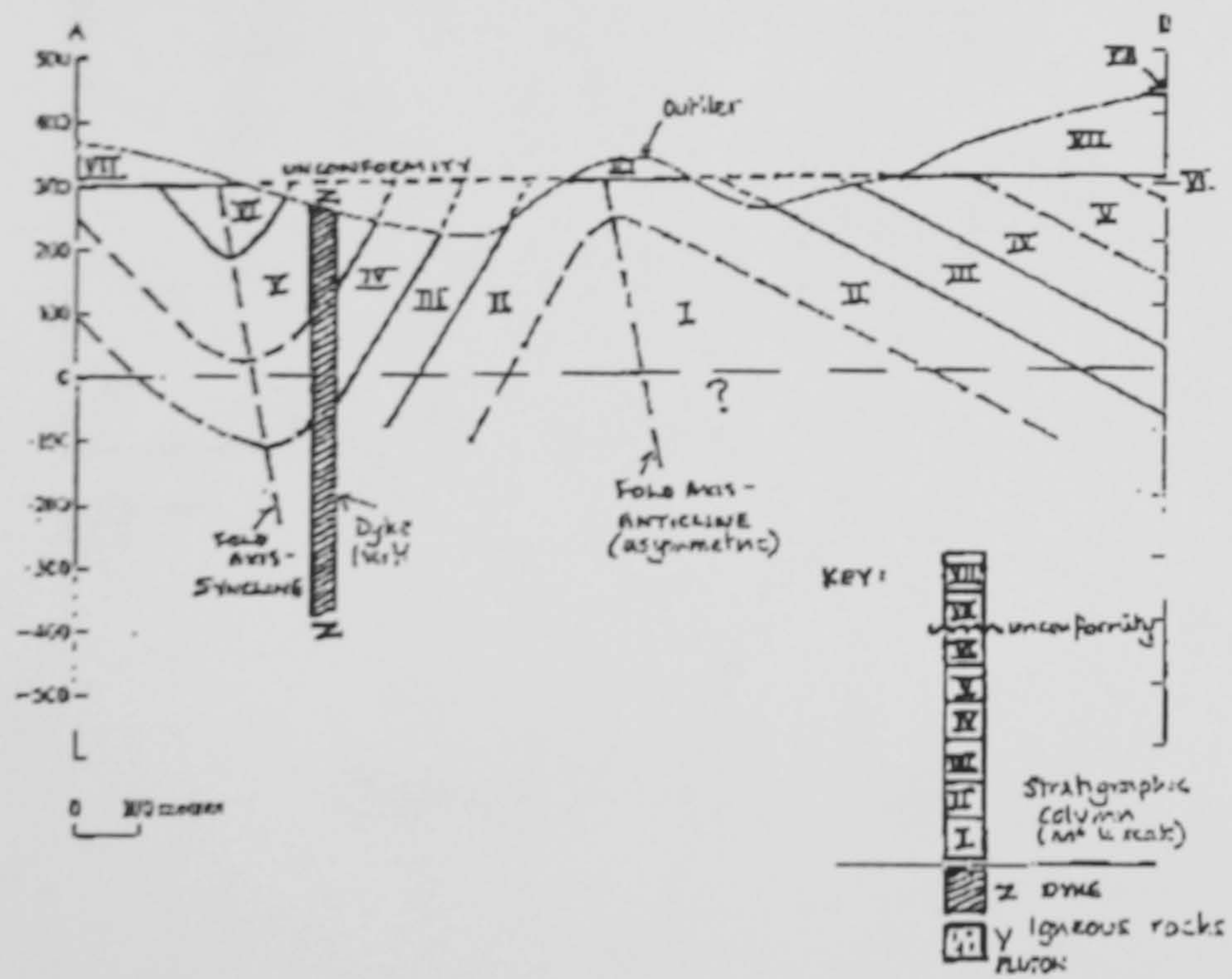
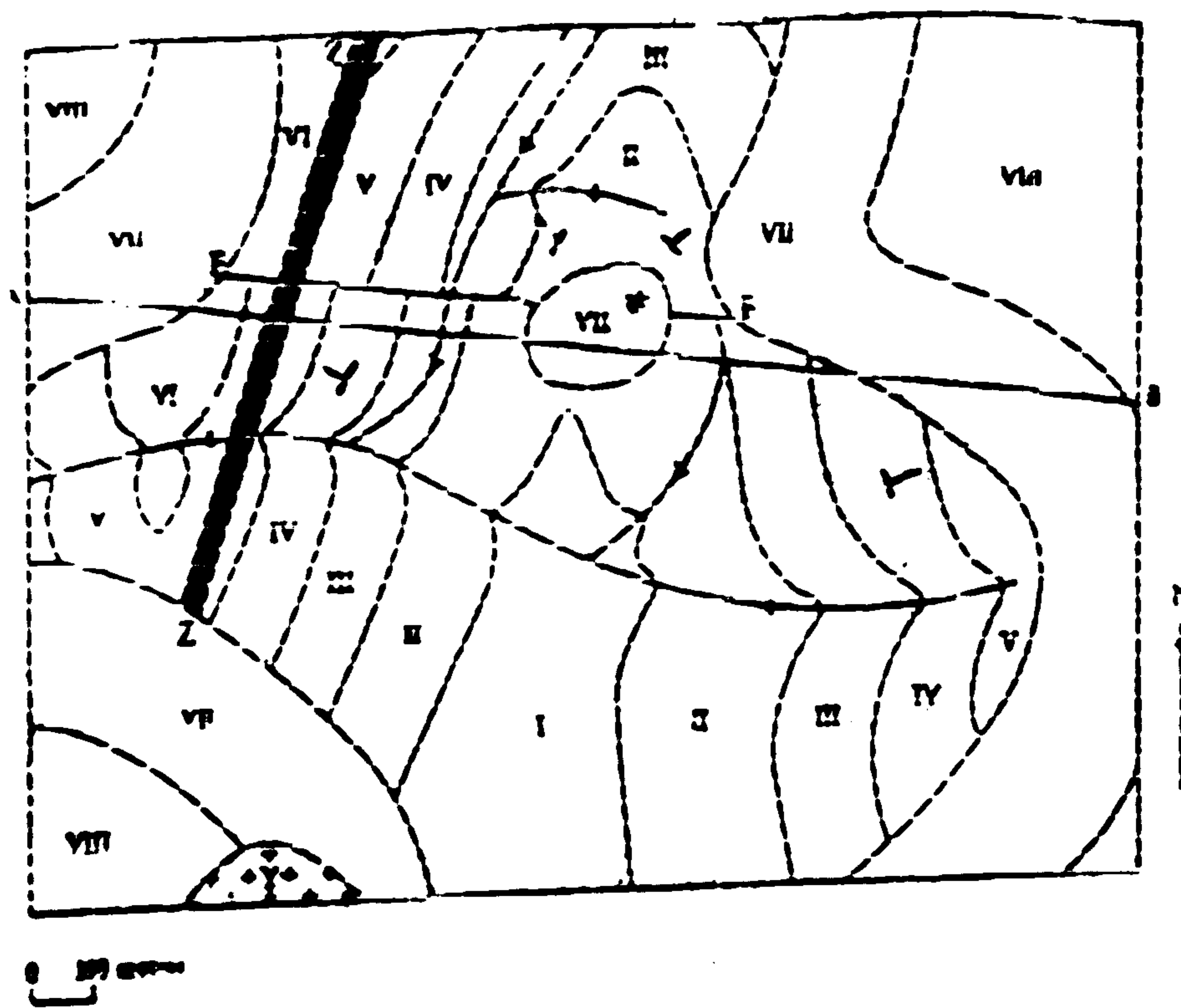


Figure 17b: cross-section Solution used in Pre and post tests

Figure 18a shows that student A has made a few correct interpretations of dip, but shows no evidence that the student knows there is a fold structure. This student did not attempt to develop a pre-test cross-section. This student seems to demonstrate a fragmented conception of geological mapping. One of the judges of the blind pre and post-tests describes the pre-test map in the following paragraph.

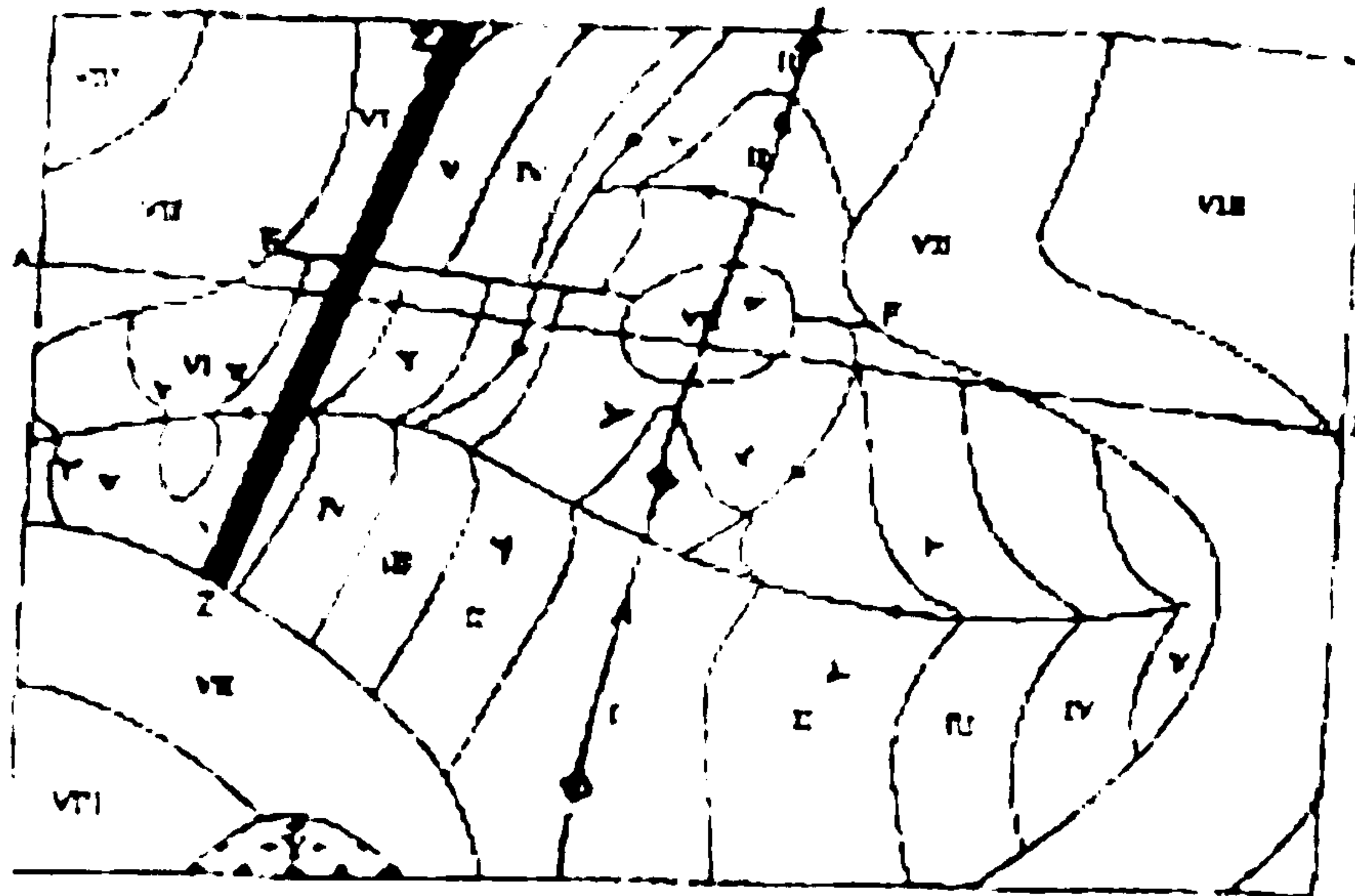
*This student has made a start on deducing dip directions correctly using the veeing rule. A lack of understanding relating these rules to the concepts seems to have prevented them from getting very far with the tasks. J2*



*Figure 18a: Pre-test map by student A*



In comparison, the post-test map analysis indicates that this student gained some insight into visualization. Figure 18b shows how the same student as above interpreted the map. In contrast to the pre-test map, Figure 18b shows that this student has correctly identified the dip directions and the antiform, but has failed to identify the synform on the west side of the map.

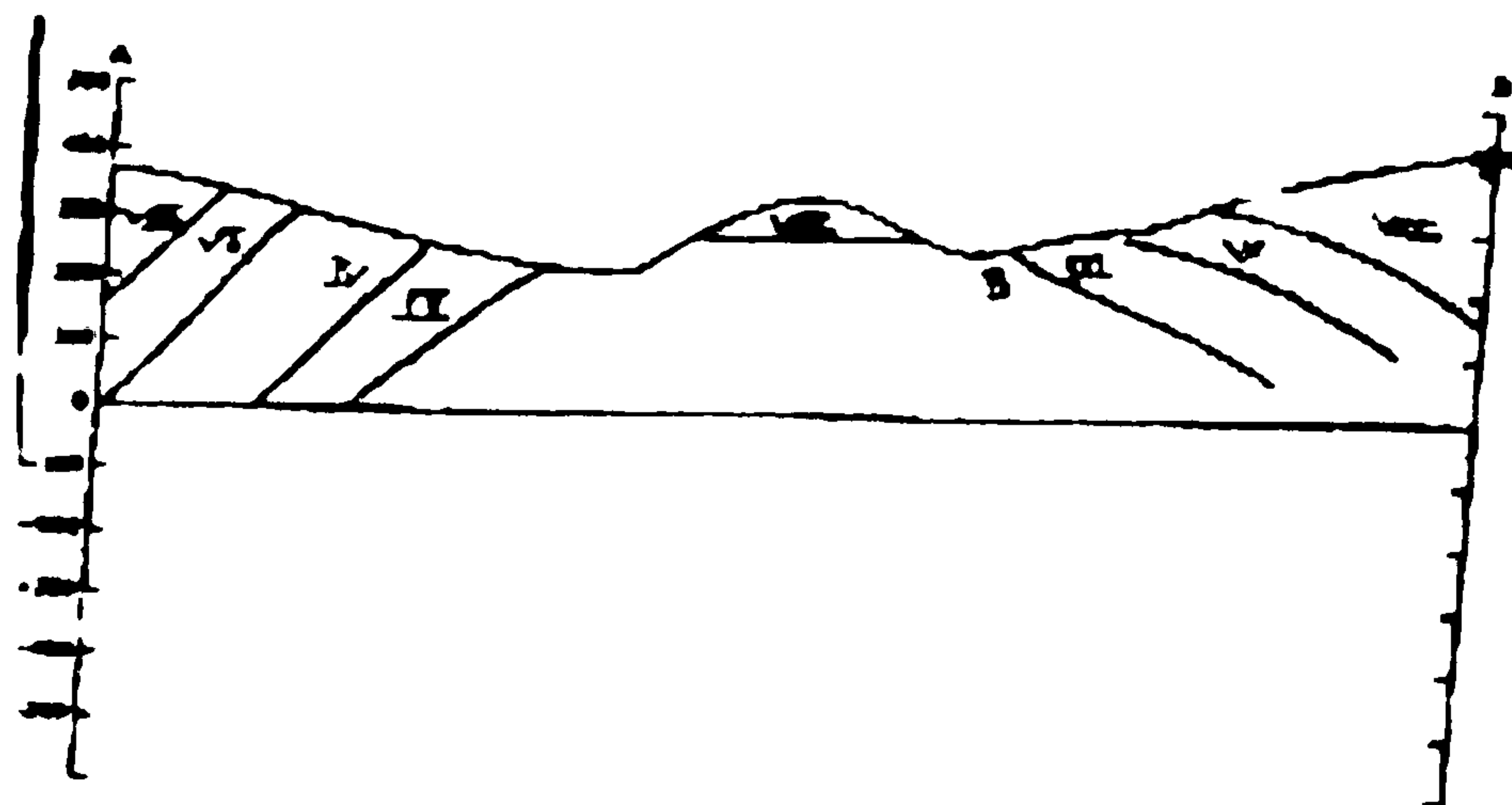


*Figure 18b: Post-test map by student A*

Figure 18c is the cross-section developed by student A on the post-test. It shows that this student has a partially correct interpretation of the structure of the antiform. However s/he has shown VII as horizontal in the middle of the profile but has not shown that VII and VIII are both horizontal beds overlying the older beds that make up both the antiform and the synform, which s/he has missed in the west. However, incompleteness is much less of a problem than incorrectness, and even though incomplete, this student shows evidence that the conceptual leap has been made to interpreting dip in terms of fold structures.

The following was an assessment of the post-test map and cross-section were made by Judge 2.

*This student appears to have gained confidence in recognizing dip directions from the veeing rule and in locating the axial plane and identifying anticline. They have gained some skills but the attention to detail is lacking. It is as if only one or more closely related concepts can be taken on board at a time. J2*



*Figure 18c: Post-test cross-section by student A*

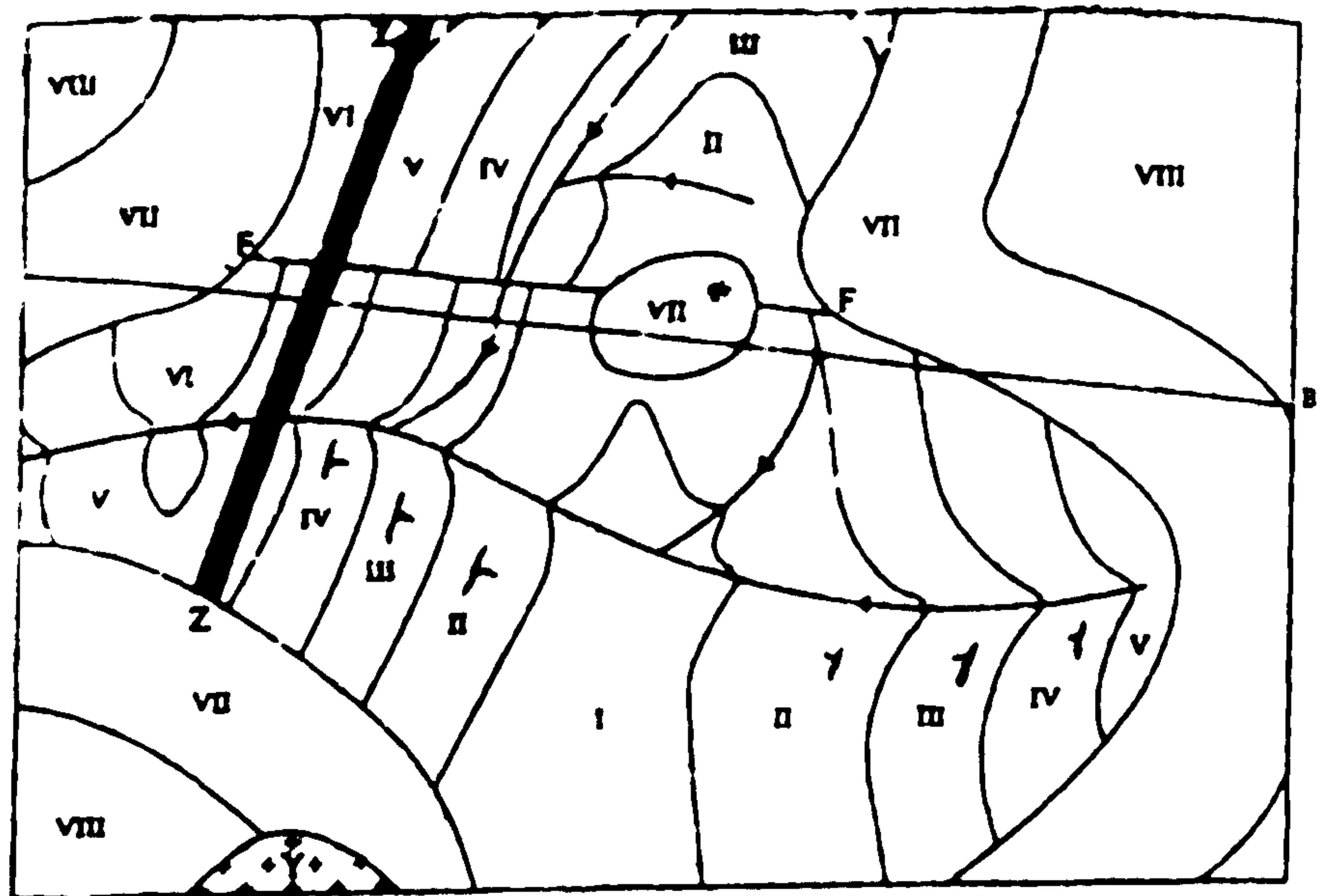
This student has used veeing to interpret the dip directions correctly where attempted but has some confusion about this rule (and its related concept) and plunge direction of the fold. They have not attempted to deduced dips on the younger strata. The anticline has been correctly identified from the dips, presumably, and its axis correctly located but not offset by the fault FF. The syncline has not been identified even though the direction of the dips is correct. It is also missing from the cross section. The unconformity at the base of bed VII has not been identified and the younger beds have been wrongly included with the anticline. This student has probably not considered the whole map and therefore missed useful evidence. The points along the line of the section have been transferred to the topographic outline probably by



following the rules without thinking about what they were in fact doing. This student seems to have begun to make connections with geological reasoning. However, the surface approach is maintained without an attempt to search for evidence for interpreting the whole map.

J2 has perhaps expected yet another conceptual leap when stating "The anticline has been correctly identified from the dips, presumably, and its axis correctly located but not offset by the fault FF.", and this concept was not covered in the geological mapping learning materials designed for this evaluation study.

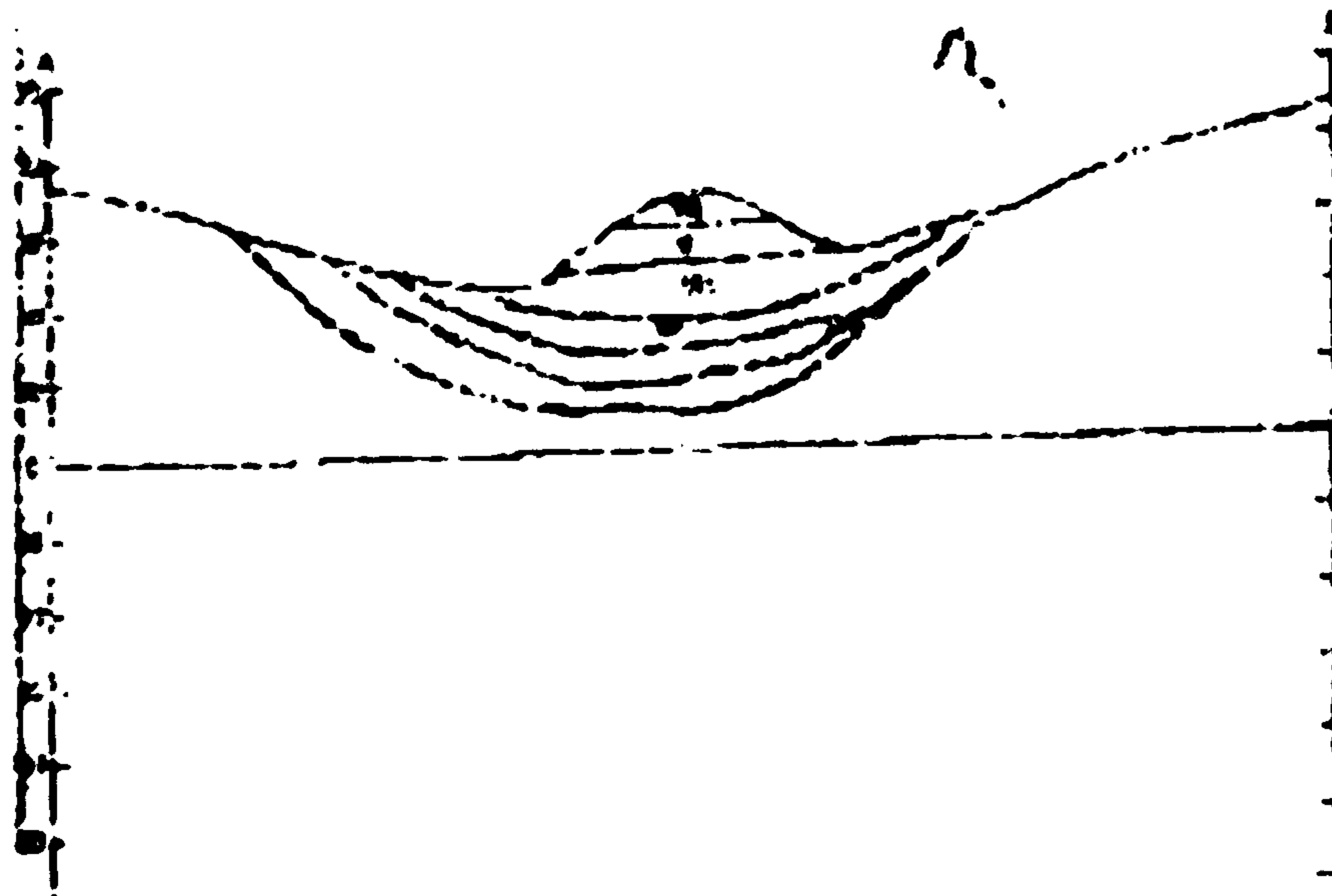
Figure 19a is the pre-test map for student B, and illustrates how a student made errors in interpreting the dip directions that directly led to misinterpreting the fold structure as a synform instead of an antiform. This student has dip/strike directions correctly interpreted on the west part of the antiform fold and incorrectly marked on the east side of the fold. This student appears to be demonstrating a fragmented conception on the pre-test, and this seems to be supported by both of the judges who evaluated the pre and post-tests.



*Figure 19a pre-test map by Student B*

Figure 19b is the pre-test cross-section developed by student B to accompany the pre-test map (Figure 19a). This student has incorrectly interpreted the dip directions, hence has developed a cross-section that shows a synform where an antiform should be. Student does not realize the boundary between VII and VI. Student can't see what to do with boundaries that do not reach the surface (those that are below the unconformable base of VII).

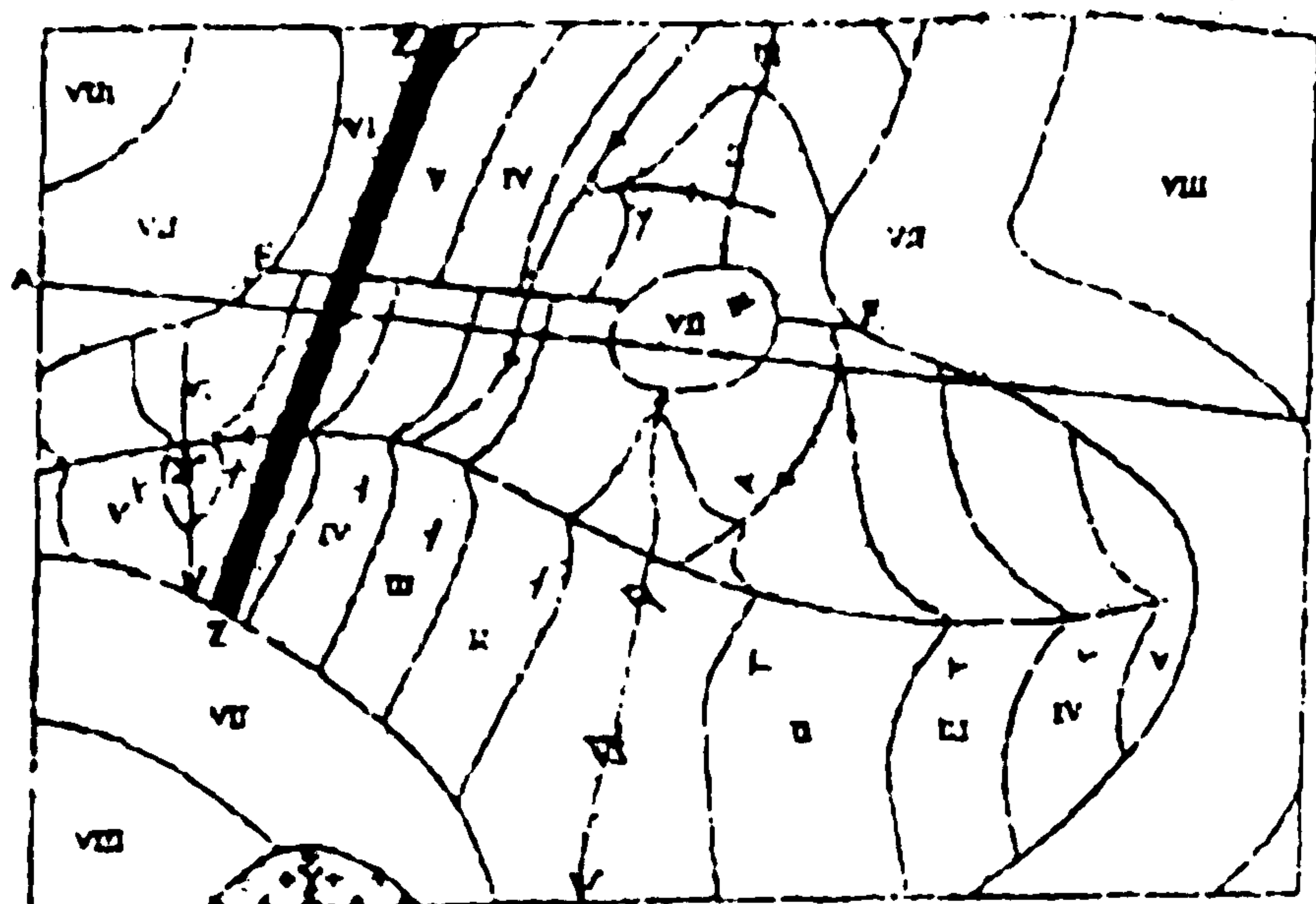
*Student has transferred positions of boundaries from the map to the cross-section correctly, but is lost after that. Student has mis-used the rules about the v-ing so has dips wrong. This student also has not taken into account the relative ages of the rocks. The evidence for this is that s/he seems to have included all the strata in one fold formation, even though it appears that s/he understands that VII is horizontal and hence younger than the others.. J1*



*Figure 19b pre-test cross-section by student B*



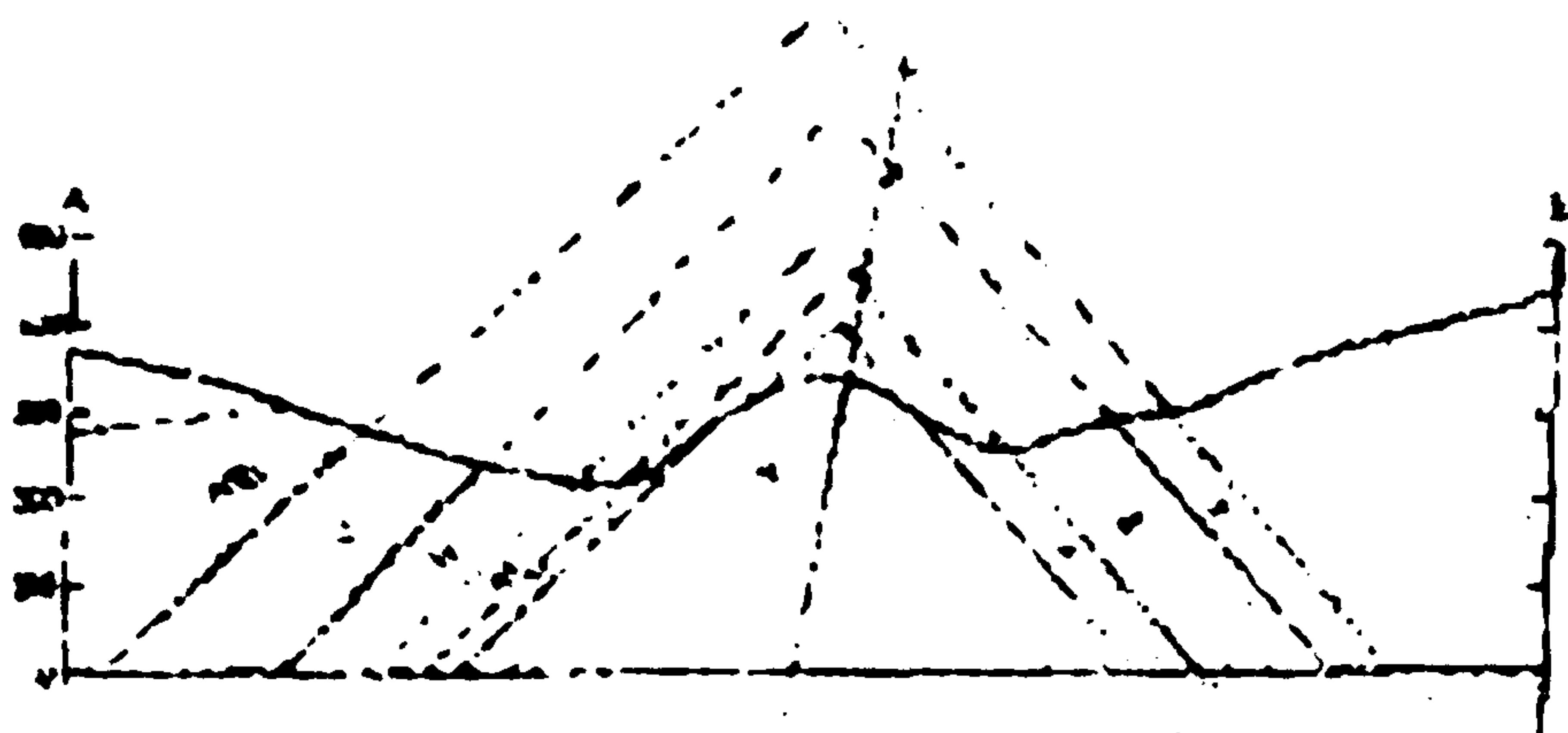
The following post-test map for student B illustrates how this student was able to make the correct interpretation of the dip/strike direction, and the correct fold types.



*Figure 19c post-test map by student B*

*However, despite saying in the pre-test s/he can visualise fault, etc., s/he has not used the relationship between the fold, fault and VII to deduce that VII is unconformable overlying the folded strata. J1*

Figure 19d is the post-test cross-section by student B to accompany the post-test map (figure 19c). Student B has used v-ing to work dip direction so has got the anticline correct (on map, except that plunge is the wrong way) and x-section.



*Figure 19d post-test cross-section developed by student B*

*Although this student has improved their ability to interpret the dip directions, and hence has the correct type of fold, s/he still is demonstrating difficulties with understanding the dimension of time. Strata VII is the youngest, having been deposited after the older strata (I - VI) was folded, yet this student has represented the cross-section as if VII is part of the fold,.*

*J2*

*This student improved the most. The only achievement in the pre-test was the correct transfer of boundaries (contacts) from the map to the cross-section. In the post-test has used the veeing rule to work out dip directions so has got the anticline right.*

*J1*



Based on the more sophisticated interpretation of the map, along with the comments of the judges above, this student seems to demonstrate a geological conception of mapping, having moved from a fragmented conception on the pre-test.

The following excerpts from the post-test demonstrate how the learning materials helped students to resolve some of their confusion:

I found this one (the post-test) much easier to understand because I finally understand the relevance of the v-patterns on streams. It is amazing how much simpler the maps become once basic principles are understood!!!

I hope I will no longer confuse the significance of v's and river flow direction.

Using the v-ing, a syncline can be seen through 6 and the antiform through 1.....1 is the oldest strata and they get younger through 2,3,4 and 5. 6 is on the axis of a syncline so it is the youngest and 7 and 8 are unconformable overlying these.

From these excerpts we see that the students considered the learning materials to have provided some support in understanding how the v-rule applies to the interpretation of dip direction, which leads to interpreting the existence of fold structures. In the last excerpt we see evidence of the development of a geological conception with the student using the v-patterns to first detect a syncline, and determines (correctly) the relative ages of the formations in the fold.

### **Questionnaire Data**

In addition to considering the pedagogical effectiveness of the materials tested using pre and post tests, I also investigated the extent to which the students' perception of the learning experience matched the intention to clarify the underlying concepts. Their responses indicated that they did consider the learning materials as clarifying for them. The majority (12 out of 13) of the students had positive comments about the materials, such as the following;

The clarity of the answers and the logical steps of progression,

The answers following the questions in case of uncertainty,

They're simple and straightforward, they explain the ideas clearly, especially the part where the geological and maps are compared, and

they gradually led into the problem so they took you with them—mostly.

Of the students who provided negative comments about the materials, only one referred to conceptual difficulties.

too basic, not complicated enough (which is when problems arise) doesn't solve my problem about identifying plunge direction

Some comments (about half) related to operational aspects of the materials, such as that the solutions in the booklet were (temptingly) close to the questions. Over half of the students rated the materials at about the right level of difficulty on a scale of 1 was easy and 5 was difficult. Only two students rate the materials as easy, and one student rated the materials as difficult.

The questionnaires also reflected the learners' perceptions of the learning experience when asked to rate the usefulness of the components of the learning materials. All the components of the materials (Exercises, diagrams and explanations, feedback) were rated as useful or very useful. This is in contrast to the ratings of the previous study (Chapter 6) where only about half of the students rated the various elements as useful or very useful.

Of most importance in reporting on students' perceptions of the learning experience was what they learned. Recall that in the previous evaluation study described in Chapter 6, most of the students (70%) reported that the materials had reinforced what they already knew. Only 9% of the participants in that study said that the materials taught them something new and 17% said that the materials had caused confusion. In contrast, none of the students in the current study felt the materials caused them to be confused about the concepts presented. Most students (12 out of 13) felt they had learned something new, for example;

I now have a clearer idea of the difference between an antiform and a synform,

the marking for the vertical strata, visualising the cut a river makes in an antiform( i.e., the antiform may be eroded),

reaffirmed synform dips towards each other,



dip direction re v-shapes...don't assume that lettering means the age of the formations,  
the v-shapes of river erosions showing dip direction,  
symbols for antiforms and synforms and when beds are vertical and no more confusion  
regarding v's and river direction.

Finally, students were asked how the materials compared with Open University course materials. In general, students considered these materials to be simpler and easier to use. Of course, the Open University materials covered a very large number of topics that the current materials didn't even touch on. The main point emphasised by students was the simplicity of these materials such as;

a bit similar but this one is simpler and easier to use,

There is so much introduced in Block 1 (the Open University materials) that useful ways of interpreting maps, such as looking for v-ing tends to get lost in among not so useful data,

easier, things laid out simply with nothing else on the page to make you lose track of what you are reading, and

These transcripts demonstrate that students perceived the learning materials as having provided simple explanations of material they had previously found difficult. The participants in the current study have expressed more positive experiences than those in the previous study, even though the actual learning materials used were identical. The main difference was that the current study used real problem maps as pre and post-test instruments. These instruments provided a task that was directly aligned to the coursework, and to the goals of the learning materials, i.e. to interpret geological maps. Therefore, these students (even the seven who did not demonstrate conceptual improvement) probably considered the experience to be very relevant to their learning needs.

This is the kind of result that supports the use of learner-centred data in instructional design, i.e. the concepts covered in the materials were focused on the particular problems that emerged from students' own experience as provided in the phenomenographic study, therefore, the level of presentation did fit well with their needs.



## 7.7 Conclusion

In the context of the new analysis, we saw evidence of qualitative improvements for six of the thirteen students' abilities to interpret maps and develop cross-sections, and this was supported by the judges who marked blind pre-and post-tests. In terms of how the improvements are interpreted as a function of movement within the outcome space, the following summarises changes in conceptual categories;

- 2 students moved from a fragmented conception to a topographic conception
- 3 students moved from a topographic conception to a geological conception
- 1 student maintained a topographic conception from the pre to post-test, and
- 1 student moved from a fragmented conception to a geological conception

The analysis of student work indicates that students who did improve had a much better understanding of both the concept of dip and how to interpret v-patterns on rivers and valleys. The results also show that students who previously confused topography with underlying geological structure had gained some insight into the difference. The learning materials provided them with techniques to apply to the interpretation of the map, such as circling the v-patterns, and identifying the folds from the regular, repeating patterns of beds on either side of an axis. The materials also provided a basis for them to understand the effects of erosion over time on a folded structure and how that erosion appears in map and plan view, an important support to the development of the understanding of time in the context of geological thinking. The materials provided a simple exercise in determining dip using a 3D view; students were able to see how the direction of dip changed when the direction of the beds changed.

However, there were only 4 students who moved from either a fragmented conception (1) or topographic conception (3) to a geological conception. This demonstrates that there is a long way to go in designing materials that will help students to change the way they acquire understanding of complex material. Had the outcome space as presented here been developed before the learning materials were designed it is likely that a larger impact on conceptual development would have resulted. For example, additional learning activities may have focused on requiring students to demonstrate how the evidence in the map would be used to develop a story of a geological area. More focus on ways of thinking about mapping that



would better distinguish between the topographic and geological conceptions would also have been helpful.

In this chapter I have identified three pedagogic factors that may have contributed to students acquiring a topographic conception of geological mapping, they are;

1. The placement of mapping at the early part of the course,
2. The use of representations without sufficient explanation of their meaning, and
3. Use of rules for teaching students to interpret v-patterns on maps.

As discussed earlier, these rules could be applied with very limited understanding of geology and result in a successful interpretation of dip direction. I contend that without the geological knowledge that will allow these rules to be meaningful, students will try to memorize them and apply them indiscriminately, sometimes getting the interpretation right, other times wrong, in a trial and error manner. The intermittent 'right' answers likely interfered with the student attempting to understand the 'wrong' answers.

An architecture of variation has been presented that shows the path of learning, with one path (the main road) leading to the development of a geological conception of mapping. The student who follows this path has correctly integrated the concepts of dip, visualization in 3-dimensions, the dimension of time in relation to geological processes, and the relationship between topographic features and geological structures. The other path leads the student to a topographic conception in which the learner attempts to integrate topographic concepts into a geological context, leading occasionally to correct interpretations, but for the wrong reasons. We have seen movement between the categories, with the majority of students in the fragmented conception category remaining there. The move from topographic to geological, though only demonstrated by 3 students shows that the learning materials did help a small number of students overcome a common misconception about geological mapping brought about most likely through a combination of pedagogic errors, i.e., that the boundaries between geological stratum on a plan view map are interpreted as elevation indicators and therefore geological structures are interpreted as topographic features, such as hills, and



valleys. The most dramatic move within the outcome space was the one student who moved from a fragmented conception to a geological conception.

Creating an architecture of variation is a difficult conceptual feat. Given the small numbers of students in the current analysis, it is inconclusive with regards to the path of learning, and only indicative of how one might further analyse the data in pursuit of a deeper understanding of where and how learners acquire their understanding of complex material.

## 7.8 Discussion

The results of the data from the current study within the context of the new analysis of the outcome space demonstrate resonance with many of the same conceptual difficulties that had been discovered in the pilot study (chapter 3). Given that students had been enrolled in the course by now for over 9 months, one might have expected that the students would have gained a better understanding of geology, and that this would have transferred into a better conceptual understanding of interpreting maps, particularly given that students had all participated in mapping activities in residential school only 2 months prior to this session. However, this illustrates just how difficult it is for students to overcome persistent conceptual difficulties, and underlines the need for rethinking the way in which we design courses.

The results of the two evaluations presented here and in Chapter 6 demonstrate that:

- students continued to maintain conceptual difficulties following 7 months and 9 months respectively of study
- students demonstrated improvement in understanding of interpreting geological mapping after used specially designed materials for 1 hour teaching,
- reliability of the analysis of the pre and post-test results were supported by judges
- allocation of the student transcripts to the categories of description using a co-judge were found to be reliable within an acceptable 80% ,
- a phenomenographic approach achieves a clear account (analysis) of students' difficulties and
- a design based on phenomenographic analysis can be used to generate successful teaching materials as tested.



The learning materials of course did not achieve complete understanding of geological mapping for students, and doing so would clearly take more time. However, the success of the approach in instructional design given this case study provides a good starting point for improving teaching and learning.

### **Methodological issues**

There are a number of methodological issues in this study worthy of note, the most important of which was the time I was able to access students. It was only possible to assemble a reasonable number of students together to carry out this study for a little over an hour. It would have been preferable to have students for two sessions, both of at least an hour long in which they would have had sufficient time to consider how they interpreted the map and to write about their experiences. Given more time, pairs of students would have worked together and there would have been some interesting interactivity to observe and analyze which would have implications for design as well.

Relying on students to be able to reflect on their difficulties is a methodological issue concerning the use of static assessment instruments, such as pre and post-test. It would have been preferable to interview the students afterwards to get more in-depth information about how the materials affected their learning. This issue is an antecedent to the difficulty of access to students as mentioned above. In future, one might consider using audio tape recording to allow students a more free-form explanation of their reasoning.

### **Study follow-up**

The tutorial continued after the study, which provided the opportunity to check the degree to which learning from the experimental materials influenced student's thinking as they continued with more complex mapping exercises. One of the maps in the tutorial which students were given had three rather unusual features: the first was a large igneous intrusion with radiating structures, the second was the existence of two vertical beds, the third was a dipping fault. The tutor, after hearing some of the problems students experienced with trying to interpret how a cross section of such a map would look, posed a question on the board that drew directly from the learning materials. "If any geological feature is affected by the topography (for example, has a vee shape in a valley) what does this tell you about the dip of that geological feature?" Students were able to discuss how the topography exposes the direction of the dip, and that for the most part, they were able to visualise that a vertical



stratum would not exhibit any v-patterns because it had no dip nor did it follow the topographic contours. She had clearly integrated the understanding of the topographic conception, and posed a question that would help the learners to make a distinction between topographic and geological structures. This provides evidence that the learning materials provided a way of thinking about interpreting maps that the tutor was able to integrate into her own teaching.

## 7.9 Implications for Improving Teaching

Ramsden (1988, pg. 21) argues that " teachers must learn about what students 'know' and apply what they discover to improving their teaching". In this study I was able to examine the gap between the academics' understanding of the nature of students' difficulties with a particular task and the reality of student difficulties that a phenomenographic analysis can reveal. Further implications for improving teaching will be addressed in the final chapter of this thesis.

One of the academics who judged the pre and post-tests articulates his frustration of dealing with students who have difficulty in visualizing in three dimensions.

*J1: I don't see why students can't visualise themselves standing in an imaginary valley, with a dipping rock unit in the valley sides, and work out what it would look like on a map from this visualisation.*

He further indicates that students should not be relying on rules to visualise, but that they should be encouraged to imagine the way geological structures would look from different viewpoints, by placing themselves beside a stream in a valley, in a region where there is a prominent bed of rock showing through the soil that is dipping upstream. He suggests that the students ask themselves questions such as the following;

*J1; How would the outcrop of this bed look to you? What sort of pattern would the outcrop of this bed make on the map? Now image the bed dipping downstream instead. How would this look? Now, what have I got on this map I'm trying to interpret and which of the two situations I've just imagined does it match.*



He refers to these as simple thought experiments that *he* uses in interpreting geological situations. This approach is an appealing idea, however, he has missed the point that it is exactly for the reason that students can't visualise, nor engage in 'simple thought experiments' that they experience difficulties in interpreting geological maps. We identified one source of pedagogic error in the Open University course materials as being supplying rules (mnemonics) before the learner had acquired an understanding of the content. This may have interfered with the learners acquiring 3-dimensional thinking.

If one were to implement the idea of thought experiments, there would be a need for some way in which students could reasonably communicate what they were and were not able to visualise, perhaps through the use of 3-D computer generated models, or even manipulable physical models. It is clearly not enough for many students who experience general difficulty with 3-D visualization and the ability to interpret maps to engage in abstract thought experiments without support.

The judges in this study were asked to reflect on how the knowledge of the analysis of students conceptions and difficulties had implications for their teaching. Judge 2 gave her insights into student difficulties that she previously had not understood, nor had she considered ways in which she might help students overcome these problems. The following was a list of points provided by Judge 2 provides evidence that the process of being involved in a learner-centred study can provide useful information that will help instructors to improve their teaching practice, although some of the points are not well developed in terms of developing a strategy to overcome the perceived needs.

- 1. The lack of connection students make between the rule and the concepts.  
This is a block to progress.*
- 2. The rules need to be understood if they are to be applied effectively; they can't be applied unless the student is confident that they are applying the right rule to the right situation.*
- 3. When an exercise gives a student a strategy to progress with a task, this needs reinforcing with more practice before continuing.*
- 4. Students need to understand the rules before they can remember them.*



Implications for teaching this course in future include the development of the kinds of materials used in this study that focus on the particular difficulties students experience, as well as the development of materials (perhaps computer-based) to promote both general 3D visualization skills, as well as specific 3D visualization skills related to geological mapping. I have seen from this study that even with the field experiences gained during residential school, some students continued to have difficulty in interpreting maps. Another implication of this study for teaching is to consider a way of better integrating the field work with learning materials. One way this could be done is focus on the conceptual difficulties in the field, now that they are known, through particular mapping exercises.

Another implication from the study is to reconsider the current structure of the course. In the current course, mapping is covered at the earliest part of the course. We have seen that students without sufficient understanding of geological concepts are unable to relate the mapping task to geological understanding at such an early stage in the course. The earliest module might best be a review of topographic maps followed by focussing on the relationship between topography and geology, the interplay of continuous processes, and the impact of discrete events. This would then build the foundation for further geological understanding. Attention to learning approaches is also indicated. One of the major skills of the professional geologist is to build a story by seeking evidence. Students should be taught this as they learn about mapping, with care being taken to disambiguate any confusion between topographic and geological terminology and concepts.

## **7.10 Reflections on the Design and New Guidelines**

Having completed both evaluation studies, this section reflects on how well the design of the materials met the intention to help students overcome difficulties with interpreting maps as described in Chapter 4. Although the overall results were positive, there were two main limitations of the design. It seems that I had fallen into a design fault that I was trying to avoid that occurs so often in instructional design, that is, reducing content to small, simple exercises but not bringing it all together to make sense to the learner in the context of a more authentic task, such as interpreting a map. Most importantly, since the outcome space was not developed until after the materials had been designed, I did not have the benefit of that



analysis to inform my design. Had the outcome space been carried out before the design, the materials would have focused more clearly on the overall conceptual difficulties than on the lower-level objectives that I derived from the earlier pilot study.

It is the main tenet of this thesis that to determine the nature of students' conceptual difficulties in an area it is necessary to carry out focused study of the students attempting to solve a particular set of tasks, and to discover and describe the quality of the responses. It follows that if one is to design learning materials that provide learning experiences for the students for whom they are intended one must study how students respond to the materials. The process of iterative testing, or formative evaluation, is a well-accepted aspect of the instructional development process, although the techniques and instruments one applies to the process vary considerably depending upon the orientation of the design and the evaluator, and what one is trying to find out.

There were many lessons learned about aspects of the design of these materials that could only be learned through studying the students who used them. The following new guidelines have emerged from the current study and fit into the **Design and Development** stages of the 4-stage model.

- Feedback should focus on the kinds of difficulties students demonstrate when carrying out the problem tasks presented in the phenomenographic study. This information can be drawn from the transcripts of the student interviews, even using some of the original language of confusion students expressed.
- The maps (or any graphical representations) must be as simple as possible, taking the details out which have nothing to do with the interpretation of folds (such as faults, dykes), as these features add only complexity to the task. The maps need to point out clearly the difference between present-day features and geological structures.
- This domain demands an interactive 3D manipulable environment in which students can discover and map for themselves the relationship between 3D at depth and the appearance on a two-dimensional representation. This is the future work that should be the natural extension of this analysis.

This chapter concludes the discussion of the geological mapping studies. In Chapter 8, a new series of studies will be presented that will address the topic of phase diagrams and the application of a phenomenographic study methodology for designing computer-based learning materials. These new studies will provide an opportunity to further investigate the design methodology.



## **Chapter 8 Phenomenographic Data in a Team-Based Learning Design**

The design of learning materials is rarely a solitary effort, particularly when the delivery will be through an electronic medium. A variety of people are normally involved in such efforts depending on the scope of the project, and may include instructional designers, content experts, media developers, project managers and evaluators. In the previous chapters on geological mapping, the design effort was predominantly carried out with a single designer with some content assistance. This served the purpose of focusing in a detailed and reflective way on how empirical data from studies of students could influence decision-making. However, we now consider how the application of phenomenographic data in instructional design might be accomplished in a more authentic design situation. This chapter will describe how the results of a phenomenographic study were used by a team of designers for a computer-based learning package on phase diagrams. The main focus of discussion will be on the process for integrating these results within a team development context. This chapter will also present the results of a formative evaluation that investigated the effectiveness of the prototype module, focusing on re-design strategies for improving the learning experience.

At the time the work described here was carried out, I was involved in developing an evaluation strategy for a Teaching and Learning with Technology Program (TLTP) project titled MATTER. The MATTER project was formed to develop computer software for use in undergraduate teaching of Materials Science & Engineering. The current study came about as part of the process of establishing an evaluation strategy to determine the effectiveness of the yet-to-be-developed computer-based learning materials. I presented the option to carry out a study of students' conceptions as a starting point for evaluation. This approach uses a broad interpretation of the term "evaluation" where evaluation is a process of optimization that can take a different form depending upon the stage of development, and the level of detailed information required to inform design decisions. Evaluation in this context is concerned then with identifying and recommending design strategies based on the experiences of learners.

The first study presented here is concerned with illuminating students' conceptual difficulties to help a team of developers to gain a picture of the student population for



whom they were intending to design learning materials, and to use the information to guide their designs at the very outset of the project. The current study was carried out to investigate conceptual difficulties that 1st year students experienced when learning fundamental concepts associated with phase diagrams. The results of the study were to be communicated to the development team in such a way that they could implement design features and ideas to help students overcome their difficulties.

As previously discussed in Chapter 3, a learner analysis study inspired by phenomenography provides the instructional designer with input to various aspects of the design process. In the case of phase diagrams, input occurred in the early stages of development; needs assessment and design specification. There is no attempt in the presentation of this study to develop a detailed outcome space as was done for geological mapping in previous chapters. The intent was to discover how the team would use the somewhat raw results in order to determine if small-scale phenomenographic efforts could be useful in design decision-making. If it were possible for the project team to interpret and use the raw results, we would go some way in addressing the concern that applying a phenomenographic approach to instructional design is too labour-intensive, requiring specialized skills that may be difficult to find.

Lessons learned from integrating phenomenographic data in the context of a team development provides a different perspective on decision-making in design, as it takes on board the analysis of study results in a broader context than for an individual effort. The chapter begins with an account of the design process and roles of the various stakeholders involved in the development of the computer-based materials. This is followed by the results of the phenomenographic study. The results of a formative evaluation of the computer-based learning materials are then presented, and the last section of this chapter discusses how the experience of using a phenomenographic approach in a team development informs design practice.

## **8.1 The Stakeholders and Design Process**

The stakeholders for this project were the people who either had a particular responsibility for the outcomes of the development effort or were the recipients of the product, i.e. the students. The process of integrating phenomenographic data relied on the ability to



establish relationships and credibility and communication with and amongst the following people.

1. *Content expert (Course lecturer).* The content expert in this project was the course lecturer who was the main contact for the evaluator (myself). She provided domain expertise, enthusiasm for the study, interfaced between the evaluator and the management team, and provided access to the students.
2. *Development team.* In this project, the development team consisted of two people, one of whom had a Ph.D. in materials science, and the other an undergraduate science degree. Both were learning to use ToolBook as a development environment and had no previous experience in designing computer-based learning materials.
3. *Management team.* The management team consisted of seven academics representing their respective institutions in the consortium project. All served as content experts in the area of materials science and were responsible for a variety of different modules that would eventually become the Materials Science on CD-ROM.
4. *Students.* The participants were first-year students were studying metallurgy at Imperial College London. They had completed the first term of their first year. A small number (5) participated in the phenomenographic study (needs assessment), and 10 participated in the formative evaluation of the prototype module on Phase Diagrams. The phenomenographic study provided a mechanism for the students to make a direct contribution to the development through sharing their understanding of fundamental concepts about phase diagrams. They also contributed significantly to the developers' understanding of navigation and interface issues through their participation in the formative evaluation study.
5. *Evaluator.* My role was to provide third-party evaluation of the teaching and learning aspects of the project. I participated in three different packages of work at three different times in the development of the project. I designed and carried out a phenomenographic study that served as a needs assessment before any development work was done. I designed the formative evaluation study and evaluation instruments for the early prototype that was developed following the presentation of the results of the



phenomenographic study. The data collection and analysis was carried out by second evaluator who authored the formative evaluation report that was delivered to the project team. My contribution to the report was to review the results before final delivery.

Each of the above categories of stakeholders thus contributed to development of the computer-based learning materials.

### **Design Process for Integrating Phenomenographic and Evaluation Data in Design**

The following summary of steps details the process through which the data from both studies was used to inform design decisions.

#### **Step One: Review Current Evidence of Content Knowledge**

I initially met with the content expert, the lecturer who was teaching the introductory course on Materials Science. Her responsibilities on the project in addition to her content expertise included hiring a third-party to design an evaluation strategy for the technology-based learning materials. We established early on that it was not well known what kinds of difficulties students experienced with regards to the course, but she suspected that students really did not understand phase diagrams very well. We reviewed the mid-term examinations in which students constructed phase diagrams, and decided to focus on having students explain what they thought these diagrams represented. We decided to proceed with a very small study with 5 students who were at an appropriate stage of the materials science curriculum.

#### **Step Two: Review and Categorize Raw Transcript Data**

The initial results were raw data in the form of transcripts of the interview between the evaluator and the student. Given the rather complex nature of the material and the lack of knowledge of the material on the part of the evaluator, it was necessary to work very closely with the content expert in order to understand the implications of the raw data. Raw transcripts were initially provided to the content expert, and I then met with her to determine her perspective on how well the students understood the material. From there, I developed a simple set of categories of difficulties into which I placed a number of excerpts from the interviews. The content expert once again reviewed the analysis, and made suggestions for clarifying the categories. The details of the study method and results are reported in Section 8.2.



### **Step Three: Further Refine and Communicate Results**

The next step was to convene a workshop for the development team and the management team where I presented the results of the study and to provide general information about evaluation processes. An animated discussion of the results during the workshop and further understanding of the nature of the student difficulties were gained. I then produced a report summarizing the findings for the development team. I also developed a plan for carrying out a formative evaluation of the alpha-test prototype modules that would result from the design.

### **Step Four: Developers Interpret Implications and Design Prototype**

Following the workshop and presentation of the summary of the results, the developers considered the implications for their design and developed a prototype. Further details will be presented in section 7.3 of this chapter.

### **Step Five: Formative Evaluation of Alpha Prototype Carried Out**

Following the development of the prototype, a small study of 9 students was carried out to evaluate the effectiveness of the learning materials and to determine if there were interface and navigation issues that were potentially interfering with the use of the materials. The results were analyzed and reported to the project team and developers. My formal involvement in the formative evaluation was to develop the pre-and post-test questions and to review the report. I was not involved in the analysis of the data.

### **Summary**

The above steps represent a high-level summary of the work that was carried out in the development of the prototype computer-based module on phase diagrams. In contrast to a solitary design effort, a development team involving a number of stakeholders was part of the design process. Team efforts have the advantage of collective intelligence that should lead to higher quality results. However, the design process can be much longer and complex due to the necessary inclusion of stakeholders in information sharing and decision-making. Including phenomenographic data in the workshop described in Step 3 stimulated lively discussion amongst the project team members about the implications of what the students transcripts revealed. Some of the comments by the academics who taught the students in the study were those of surprise, as they assumed that the students would learn



what they had taught. Having the transcripts there to demonstrate that this assumption is ill founded was a good starting point for discussions about one might integrate these findings in the design of the computer-based module.

## 8.2 The Phase Diagram Study

This study was carried out approximately 2 weeks after students had finished an examination of the first term work on phase diagrams. I met with the course lecturer to review the exam results to see if we could find an evidence of difficulties that students were experiencing with the course material. However, the exams were focused on phase diagram construction, where students were given the parameters for the development of the diagrams. The lecturer was unable to determine from the exam on what basis the students who did seem to be having difficulties with constructing the diagram were unable to do so. This is a demonstration of how assessment does not always measure student understanding. The lecturer had some sense that the students did not clearly understand what she was attempting to teach, but could not articulate it. The opportunity to carry out a qualitative study was welcomed by this lecturer as a way of coming to understand how students were interpreting her teaching. The involvement and enthusiasm of this lecturer was critical to the success of presenting the results to the larger team.

Five first-year students were selected to participate by their course lecturer, representing a range of abilities as demonstrated on exams and coursework. Their exam results represented a range of scores. In addition to progress in academic work, these students had participated in a Study Skills Inventory, and the summative scores are included here as a point of interest. However, the lecturer who was very enthusiastic about using the inventory results in her teaching did not have the source or reference to the inventory. She was convinced that by knowing the inventory scores, she would be able to identify students who needed extra help. As this study will show, the inventory score did correspond with students' qualitative understanding of the complex concept of phase diagrams. However, the Study Inventory cannot tell us anything about the nature of the difficulties that the students might experience, or indeed what kind of teaching strategies might be designed to help them overcome these difficulties. The following table summarizes the student profile information gathered by the tutor to demonstrate the variation between measures for the



students selected for the study. Later in this chapter I will come back to the student profile information when looking at the transcripts for specific students.

In each category each student is given a relative rating according their position within the group; 1st indicates the highest rank and 5<sup>th</sup> the lowest rank.

Student	Exam		Coursework		Inventory	
		/Rank		/Rank		/Rank
S1	59.77	/ 4th	89.29	/ 1st	4	/ 2nd
S2	85.23	/ 1st	78.29	/ 3rd	5	/ 1st
S3	72.04	/ 2nd	85.14	/ 2nd	1	/ 3rd
S4	62.46	/ 3rd	72.79	/ 5th	1	/ 3rd
S5	51.58	/ 5th	76.21	/ 4th	1	/ 3rd

*Table 9 Student participant profiles*

<p>Inventory scores  Key:  1= at risk  2= below average  3= average  4= above average  5= top performer</p>
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The students were asked if they wished to volunteer. The interviewer prepared a list of key questions and points to bring out in the interview and each student was interviewed individually. Each session lasted about 45 minutes and was audio recorded. The interviewer asked a few preliminary questions about their academic background, and how they felt about their progress on the course so far, and any particular problems they were experiencing.

The interviewer explained that the purpose of the study was to gain understanding of any difficulties students had in understanding phase diagrams that she was not looking for the 'correct' answer, but to gain insight into the way they thought about the subject. The

interviewer also said that the purpose of the interview was to assist us in designing computer assisted learning materials for first-year students. The interviewer also told the students that she was not a materials scientist, and that they might think of the interview as an opportunity to teach her about what they knew, and that she would ask for points of clarification. Students were also told that the results of these interviews were strictly confidential and that they would not have any impact on their marks on the course.

In general, students appeared fairly comfortable with the interview situation, although initially there may have been some concerns about the recording devices, but were reassured when they knew the instructor would not be involved, nor would she know which of them said what in the interviews.

### **The Study Task**

Students were asked to consider a phase diagram for silver and copper as in Figure 20 below. The interview proceeded from the opening question "What is a phase diagram?" The intent was for students to explain what they knew about the significance of the phase diagram, and the relationship between the phase diagram and related concepts, such as free energy and equilibrium. At the end of the interview, a new phase diagram for silver and copper was given to the students that did not have the labels for the phase regions. Students were asked to label the phase regions of the diagram.

A phase diagram maps the ranges of composition and temperature over which particular phases are stable in a given system of materials. It shows what phases are present at equilibrium in a system under various conditions of temperature and composition. These diagrams are based on the interactions between atoms and/molecules. The phase diagram provides the metallurgist with a blueprint of alloy systems from which one may anticipate at what compositions alloys are likely to have useful properties. (Cottrell, 1967)



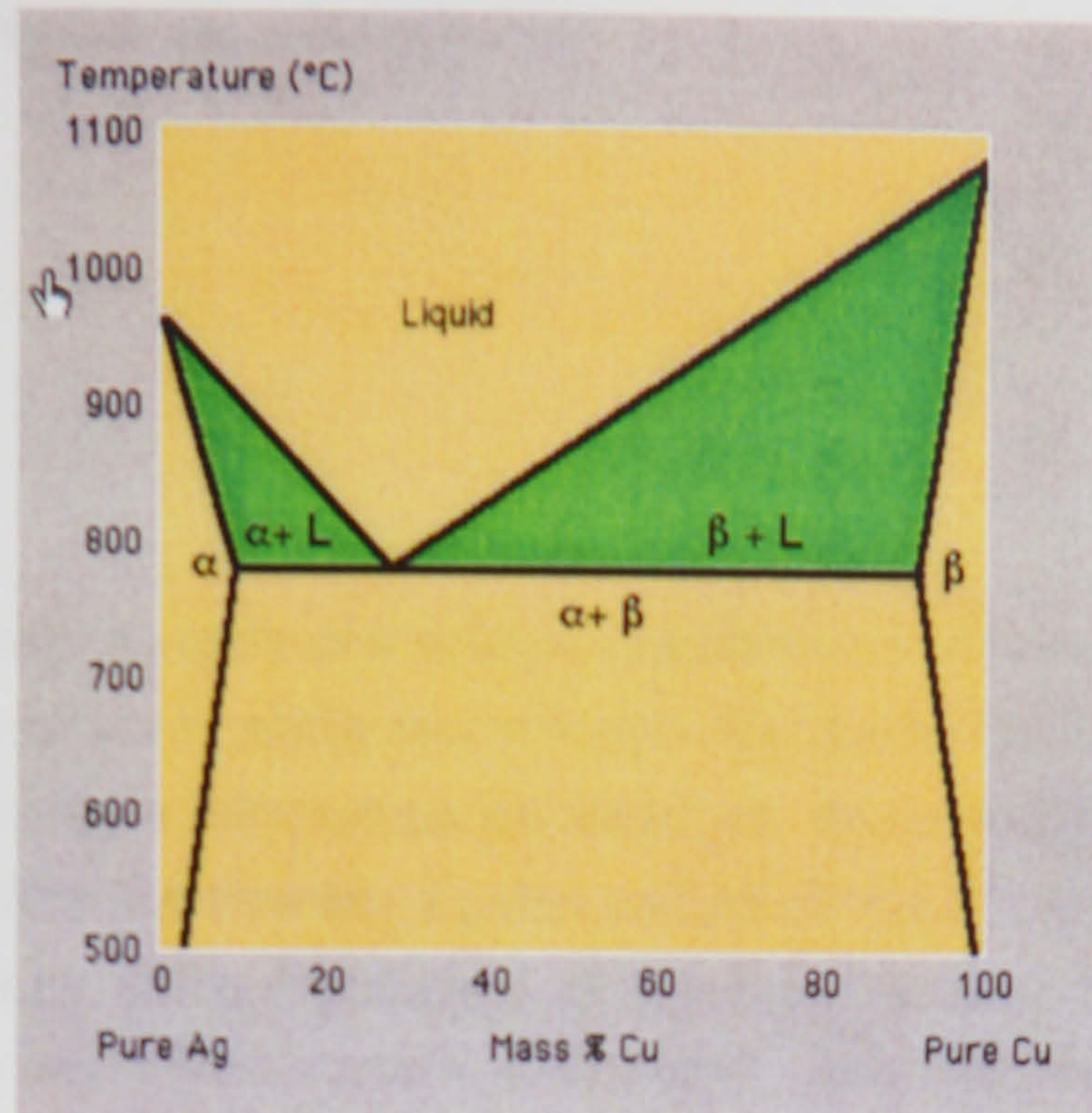


Figure 20 Binary Phase Diagram for Silver and Copper

Figure 20 is a binary (two components) phase diagram representing the phases that exist for silver (Ag represented by  $\alpha$ ) and copper (Cu, represented by  $\beta$ ) according to two variables; temperature and composition. A phase is the portion of a material [alloy] whose properties and composition are chemically homogeneous and which is physically distinct from other phases. (Porter & Easterling, 1965) For example, the liquid phase which forms when mixing Silver and Copper at a high temperature is homogeneous and one could not distinguish the two elements within that phase. The liquid phase is physically distinct from the solid phases of the system.

The 'phase regions' of the diagram denote areas where one or more phases exist in equilibrium for a range of temperatures and compositions. Figure 20 represents three phases, i.e. three chemically homogeneous and physically distinct states;

- $\alpha$  is alpha ( based on Silver) for one solid component
- $\beta$  is beta (based on Copper) for the other solid component
- L is Liquid



The remaining phase regions are defined below.

- $\alpha + \beta$ ,
- $\beta + L$ ,
- $\beta$ , and
- Liquid.

For example, alpha and beta exist as a solid in equilibrium in one of the phase regions. It does not represent a mixture of alpha and beta into one phase. This notation caused some students to have difficulty in interpreting the diagrams. As we will see, the students were confused about the difference between a *phase* and *phase region*. Perhaps this was due to the lack of understanding of the significance of a phase, or perhaps this was partly due to the notation. A novice might think that  $\alpha + \beta$  are mixed. This is further explored below.

### Results

The following categories of difficulty were developed in consultation with the lecturer who was teaching an introductory course to Imperial College students. The intent here was not to develop an in-depth analysis of the categories, but to develop a few reasonable categories within which the transcripts could be placed to present them to the development team for further discussion. The plan was for the development team to further develop the categories with us during a workshop, and to further consider the implications for these results in their design. They are presented here with illustrative quotes from student interviews in much the same way as they were presented to the management team.

**Expert Conception: Phase diagrams are static state representations of composition and temperature.**

The following excerpt is an example of how one learner explained the expert conception of phase diagrams.

S5: If you have reactions between mixing of lead and tin and you need certain compositions to make certain alloys, so it gives you certain properties or certain microstructures for those properties, and phase diagrams determine at what temperature should you mix the two compounds and at what compositions do you need..



**Potential Conceptual Difficulty: Phase diagrams are dynamic representations of changes over the continuum of time**

The following excerpts demonstrate how the dimension of time and its relationship to temperature confuses many students;

S3: ....a specific temperature and specific composition where you get Alpha which is based on solid A, Beta which is based on solid B, and the liquid, all co-existing together so you get dendrites of primary Alpha, dendrites of primary Beta but they'll sort of be in this eutectic matrix which is a mixture of both of them. And it is a unique point in which only exists for a small amount of time and if you drop the temperature below that then the liquid will solidify out to both Alpha and Beta, so you get this phase here of both Alpha and Beta.

S3: That's the whole point of the phase diagrams really.....changing is going on all the time....

During discussion with the management team, the experts tried to come to some understanding of why the learners would consider the phase diagrams as representations over time. The experts concurred that the key word or concept is "equilibrium", as in "equilibrium phase diagrams", or even "equilibrium diagrams". These show the EQUILIBRIUM constitution of an alloy of given composition and temperature. If a system is in equilibrium (i.e. it is stable) it will not change with time. Therefore time is not necessarily a factor in equilibrium phase diagrams. However, students are taught that in order to *construct* phase diagrams empirically, a range of alloy compositions were melted (e.g. Cu with 10%, 20%, 30% Ni, etc) and cooled VERY SLOWLY, to achieve conditions as close as possible to equilibrium (but not REAL equilibrium). The temperature of the material was monitored and plotted as it cooled as a function of time to obtain a cooling curve. When a transformation occurred (e.g. solidification), discontinuities in the cooling curves were observed. Therefore constructing phase diagrams is the result of plotting all the transformation temperatures for different compositions.

Metallurgy students do these cooling curves in lab experiments. They observe things changing with time. They then have difficulty in integrating these laboratory experiences to terminology used in theoretical lectures and may mistakenly connect equilibrium with processes that change with time. This explanation of the potential source of the difficulty

for students is an example of a potential source of pedagogic error in the teaching materials where the explanation about the relationship between cooling curves and equilibrium phase diagrams provided to the students was insufficient in helping them to overcome the processing of equilibrium as a concept that was associated with dynamic change, a conception that caused them difficulty in understanding the phase diagram representation.

The second difficulty revealed by student explanations of a phase diagram was in understanding the difference between the concept of a phase and a region on the diagram.

**Expert Conception: Phases are homogeneous portions of matter. In the case of alloys, they are homogeneous based on the crystal structures. Phase regions are the areas in which a phase or number of phases may exist in equilibrium that correspond to a particular composition and temperature.**

Evidence from the student transcripts for the expert conception is as follows;

I: Okay, can you tell me what you think a phase is?

S4: A homogeneous portion of matter. It is like the smallest part of the material, if you isolate the smallest part, it is indistinguishable from the other smallest parts of that material.

**Potential Conceptual Difficulty Phases are represented by phase regions**

Evidence for the potential difficulty shows the S3 talking about mixing phases, which is incorrect. However, he does get to the correct number of phases in the end. Where alpha and beta are shown together, they exist as separate phases in equilibrium within the phase region of the diagram.

S3: .....Beta and the liquid state. But up here you've just got liquid on its own, which is one phase. Then coming down here, you've got liquid and alpha mixed together, which is another phase. Alpha is based on the solid a, and here you've got liquid and Beta. Beta is based on the solid b, and down here you have alpha and beta combined together. Then here you just have solid alpha and solid beta here. So you have three different phases altogether.



The above conceptual difficulty is also an example of pedagogic error related directly to the representation. Since the learners did not fully understand the basis for a phase diagram, they made faulty assumptions about the meaning of the various conventions used in the visual representation.

The last conceptual difficulty presented to the management team concerned the term Eutectic.

**Expert Conception: The Eutectic is the point at which 3 phases can exist in equilibrium.**

The following transcript excerpt demonstrates a conception of the Eutectic that is in line with the expert view.

S3: ...equilibrium is just a stable state where you've got things coexisting together. I suppose you would say the equilibrium point is the eutectic point where all three phases coexist together.

A number of students talked about the Eutectic as a phase, in contrast to the idea that three phase exist in equilibrium at a particular temperature and composition.

**Potential Conceptual Difficulty: The Eutectic is a phase.**

I: Okay, can you tell me what you think a phase is?

S4: ... like there are three separate phases existing in this phase diagram which are.....no there's two, there's solid, liquid and the eutectic. This is the eutectic here, which is like the unique composition of alpha, Beta and the liquid state.

The above demonstrates that this learner is experiencing difficulty in identifying all the phases, and is confusing the eutectic point with a phase. The difficulty appears to be another example of pedagogic error due to the lack of clarity of the teaching of concepts and their relationship to one another.

## **Summary**

The above were the main categories into which the student transcripts were organized and presented to the management group. The group discussed each of the categories and tried to come to some understanding of why students were experiencing these difficulties.

A further conceptual difficulty with a key concept was demonstrated by students who were uncertain of how free energy relates to phase diagrams. Free energy is a topic covered in a thermodynamics course the students were studying during the same term as the materials science course.

When asked to explain free energy, students were uncertain

S3: Not really, no. I think it is one of those things like quantum theory when if you think about it too hard you don't understand it at all. If you just accept.....that like the free energy of the system is like the enthalpy and the entropy of that system....so the enthalpy is like the heat energy and the entropy is like due to the bonding....if you just think about it like that and it's just sort of a figure which is a physical quantity which allows you to determine what is going on in the entire reaction.....if you think about it too closely it doesn't really mean anything....it is just one of those things which is defined and you accept it.

In addition to terminology, the students were asked to relate the theoretical phase diagram concepts to a real-world example in order to further explore their understanding of the meaning of a phase and a phase diagram. They were asked how many phases would exist if one were to mix oil and water.

S3: Well, they're miscible aren't they, so you'd only get the one phase, cause they are mixed together. Well, normally you don't think about liquids because these.....metals at room temperature are normally solid so you're not really so interested in the liquid because something which is a liquid at room temperature like mercury is not really any good to you cause you're wanting things for structures and wiring and that sort of thing so you're looking at the solids.

Oil and water are not miscible and so the above is incorrect. Although metallurgists are indeed more concerned with solid states, the concept of two phases existing in equilibrium



is an important part of understanding how to interpret a phase diagram. In the following excerpt, the learner is asked how many phases would exist when you mix alcohol and water, which are miscible.

S5: Well, you'd have a mixture so you would have three phases there, you'd have water, alcohol, and water and alcohol.....you can have a liquid of water and alcohol then you would get a mixture. A phase diagram.....I think you have three phases in that case.

S4: You'd have a gaseous,.....three....alcohol, just water and then the mixture of alcohol and water.

The above is incorrect because the mixing of two miscible liquid substances would form a single liquid phase. The above transcripts demonstrate that the students could not explain how common, everyday examples of a binary systems (oil and water, alcohol and water) would be represented as phases. This could be because the study of metallurgy is concerned mainly with solid phases, where two components most commonly exist together. However, these excerpts also show that conceptual difficulties and misunderstandings that students experience when learning about phase diagrams hinder their ability to generalize their knowledge to a different context.

At the end of the interview, the students were given the phase diagram for Copper and Zinc that had the labels removed from the phase regions. They were asked to provide the appropriate labels. All but one of the students (S5) was able to correctly label the regions. For the one student who could not, they had used the component abbreviations in place of the generic component labels, or the Greek symbols  $\alpha + \beta$ .

### **Summary of Study Results**

The phase diagram study resulted in three main categories of difficulties, one related terminological difficulty, difficulty in generalizing knowledge of phase diagrams in metallurgy to a common, everyday binary system, and confusion about where to use symbols associated with components versus phases.

Table 9 outlines a number of measures; exam scores, coursework scores and study skills inventory scores. Each student was given a ranking for each measure. Students S1 and S2 did not demonstrate any particular misconceptions. On the previous measures, S1 had a low



exam score, the highest coursework score, and was rated as above average in the study skills inventory. Similarly, S2 rated as a top performer on the study skills inventory, demonstrated average coursework and rated as the highest performer on the exam. For the remainder of the students who did demonstrate conceptual difficulties, the study skills inventory rated them as at risk. Their other measures included the lowest scores for exams and coursework. It appears therefore that the study skills inventory did correctly identify students at risk when it came to their conceptual difficulties. However, in order to use inventory indicators, one must investigate further as to the nature of students' difficulties. It may be possible to use an inventory in advance of a phenomenographic study as a tool for identifying students who may be at risk of having conceptual but not as an indicator of the kinds of difficulties students will experience.

### **8.3 Design implications drawn by the developers**

We now look at the how these particular design specifications were realized in the final prototype. In section 8.2, the integration of the phase diagram study data in the team development cycle was described in 5 steps. Step 4 in the design process focused on the developers' interpreting the student transcripts. The following information is taken from the current MATTER website and briefly describes the impact of the study on the design of the materials.

*This module has been designed as a basic introduction to many of the concepts associated with phase diagrams. As such, little or no pre-knowledge of phase diagrams is assumed. Before developing the software, a series of interviews with a range of 1st year UK materials science students was conducted with the aim of identifying the major areas of conceptual difficulty in the area of phase diagrams. The main results of these interviews are summarized as follows:*

*- The concept of time was often associated with equilibrium phase diagrams, in that equilibrium alloy constitution, microstructure, etc. were described as varying with time, rather than with temperature. This is an understandable, albeit undesirable misconception, which probably results from the study of microstructure change in alloys during cooling.*

*- Nearly half the students had difficulty in distinguishing between the terms phase and phase region (on a diagram).*



*- Common misuse of the terms component (usually denoted by capital letters, A, B,...) and phase (denoted by Greek letters  $\alpha$ ,  $\beta$ ,...).*

*- Inability to define the terms constitution, equilibrium, phase satisfactorily.*

*In designing the software, deliberate attempts have been made to divorce the concept of time from that of equilibrium constitution. In the section Thermal Analysis, a series of cooling curves (temperature - time axes) are 'collapsed' into vertical lines so that only the transformation temperatures remain - it is stressed that time is no longer a consideration.*

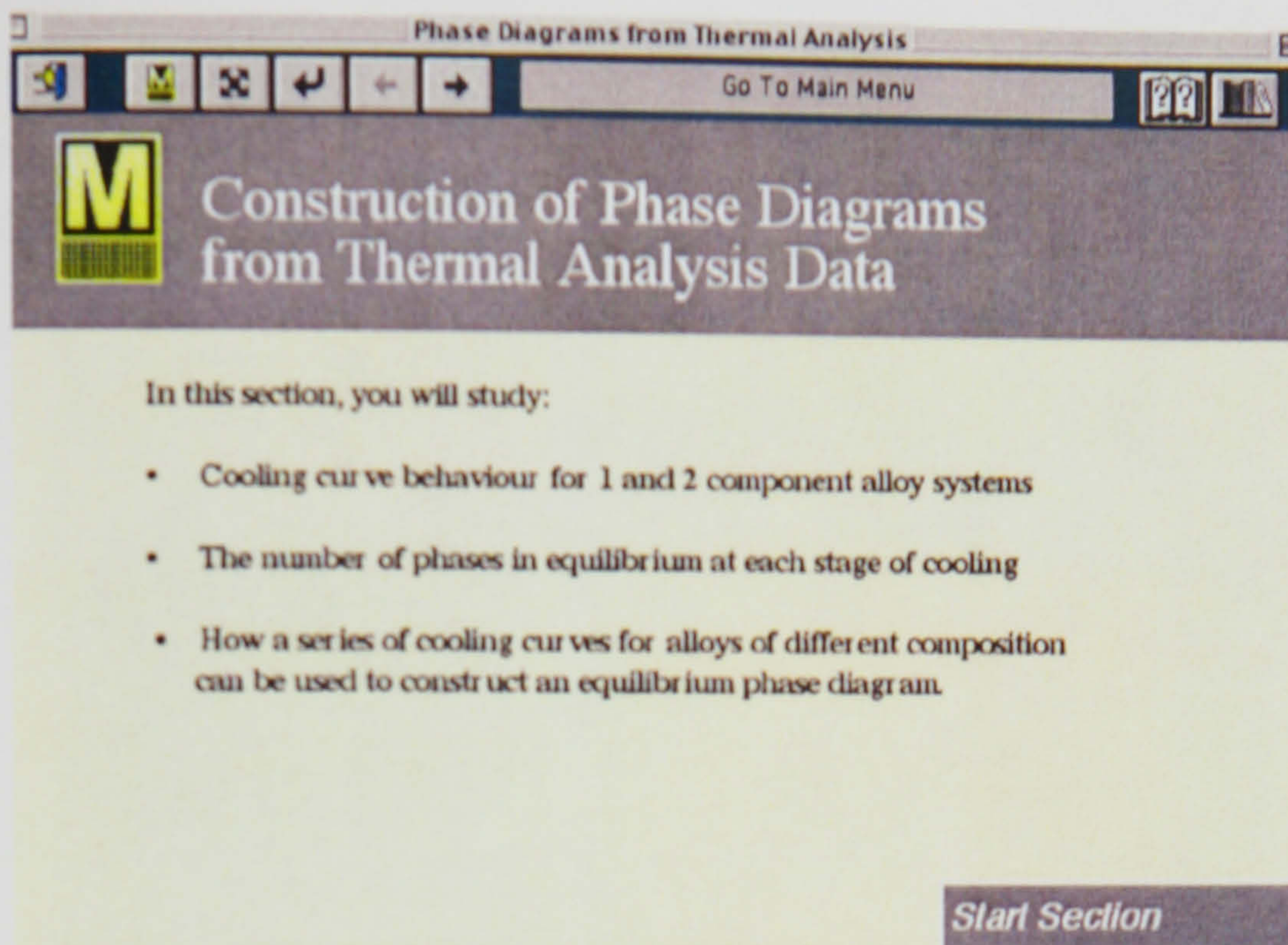
(<http://www.matter.org.uk/matscicdrom/manual/pd.html>)

The developer identified two additional terms that were not reported in the phase diagram study. From his reading of the transcripts and in his discussions with the academics on the project team he believed that students had difficulty with equilibrium and constitution. Based on his expertise in metallurgy, the subtleties in the explanations provided evidence to him that students did not have sufficient understanding of these terms and therefore he listed them here.

In order to illustrate the design strategies, this section will provide a series of screen shots from the prototype materials from the MATTER CD / version 2.1 An Interactive Learning Tool for Students. This program is an interactive tutorial designed to teach students how to interpret phase diagrams. It is one of 19 topics on Materials Science, and was the first in the series to be developed. The following is the first screen introducing the learning to phase diagrams.

This module uses a variety of visual representations that allow the learner to manipulate parameters. On many screens, the learner can point to the representation and labels appear. The blue highlighted words indicate terms that are in the glossary. Figure 21 introduction to thermal analysis data, i.e. cooling curves.





*Figure 21 Introduction to Thermal Analysis Data (cooling curves)*

The following sequence of screens are intended to show the learner how phase diagrams are constructed from thermal analysis data. In order to understand this set of sequences within the context of the conceptual difficulty related to the dimension of time, refer to page 200 of this chapter.



The role of the dimension of time is explained in terms of how cooling curves are constructed in Figure 22. The learner is invited to see how these curves appear. This activity is intended to help learners to understand the role of time in the development of cooling curves, to demonstrate where time fits within the context of phase diagrams.

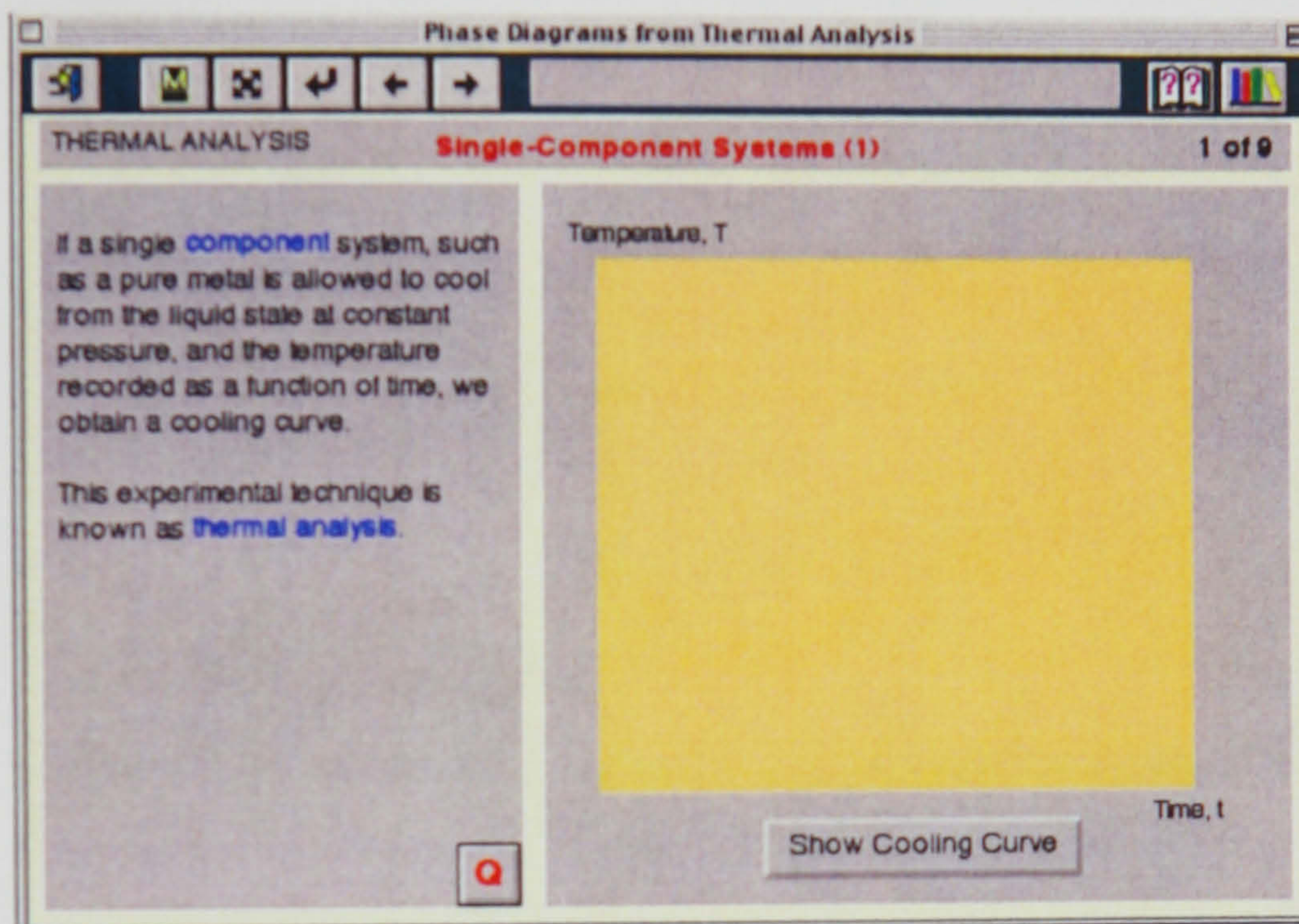


Figure 22 Single Component Systems



Figure 23 displays the cooling curve for a single component system, showing on the x-axis temperature and time on the y-axis. Following this demonstration, the Q button takes the learner to a series of questions to consider, and the sequence ends.

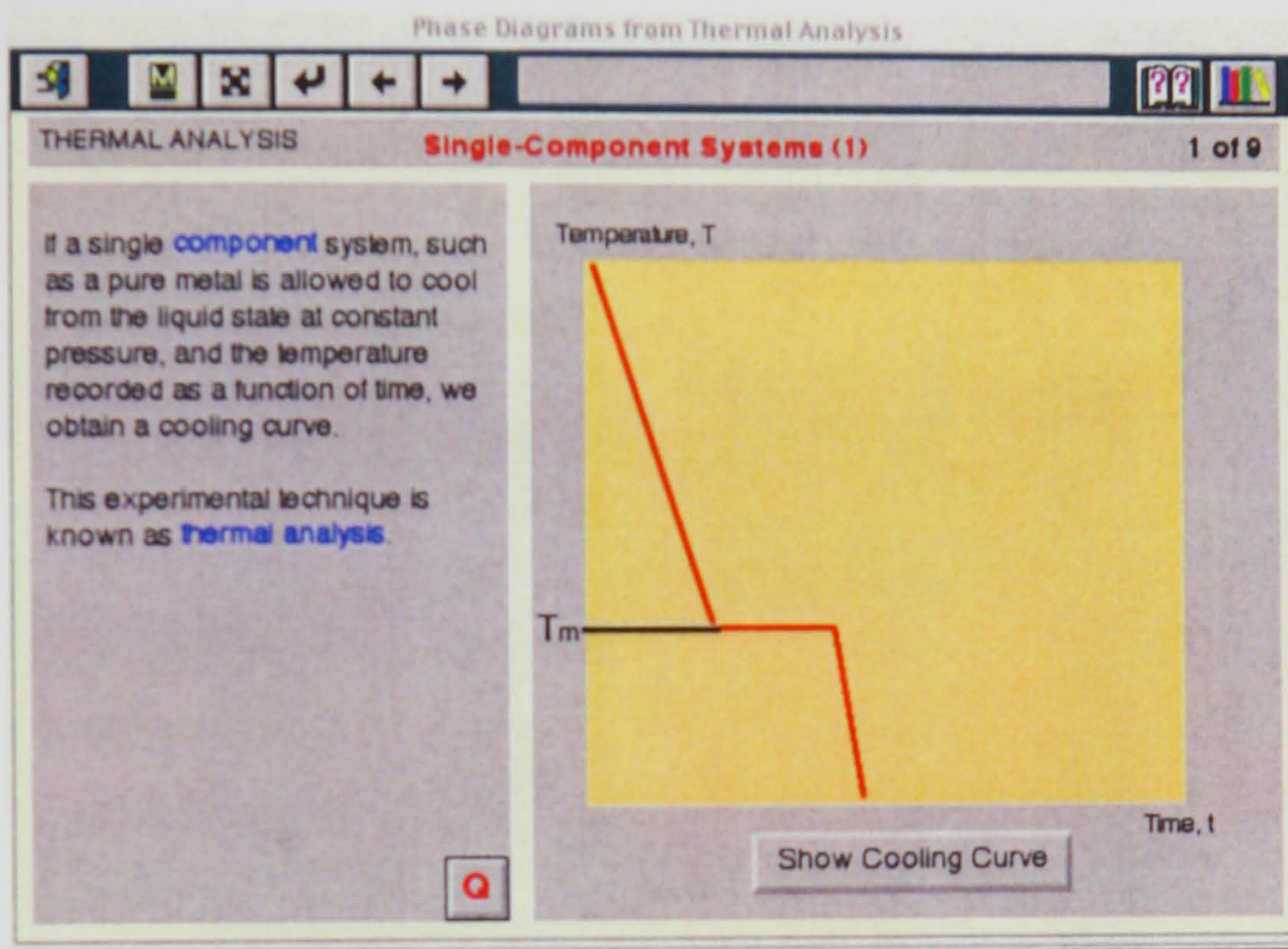


Figure 23 Single Component System Cooling Curve



Figure 24 is presented later in the module, and is concerned with binary compositions which are constructed from a range of cooling curves. The module represents the cooling curves in a similar way as above. Here the learner is introduced to the relationship between the curves and the construction of an equilibrium phase diagram.

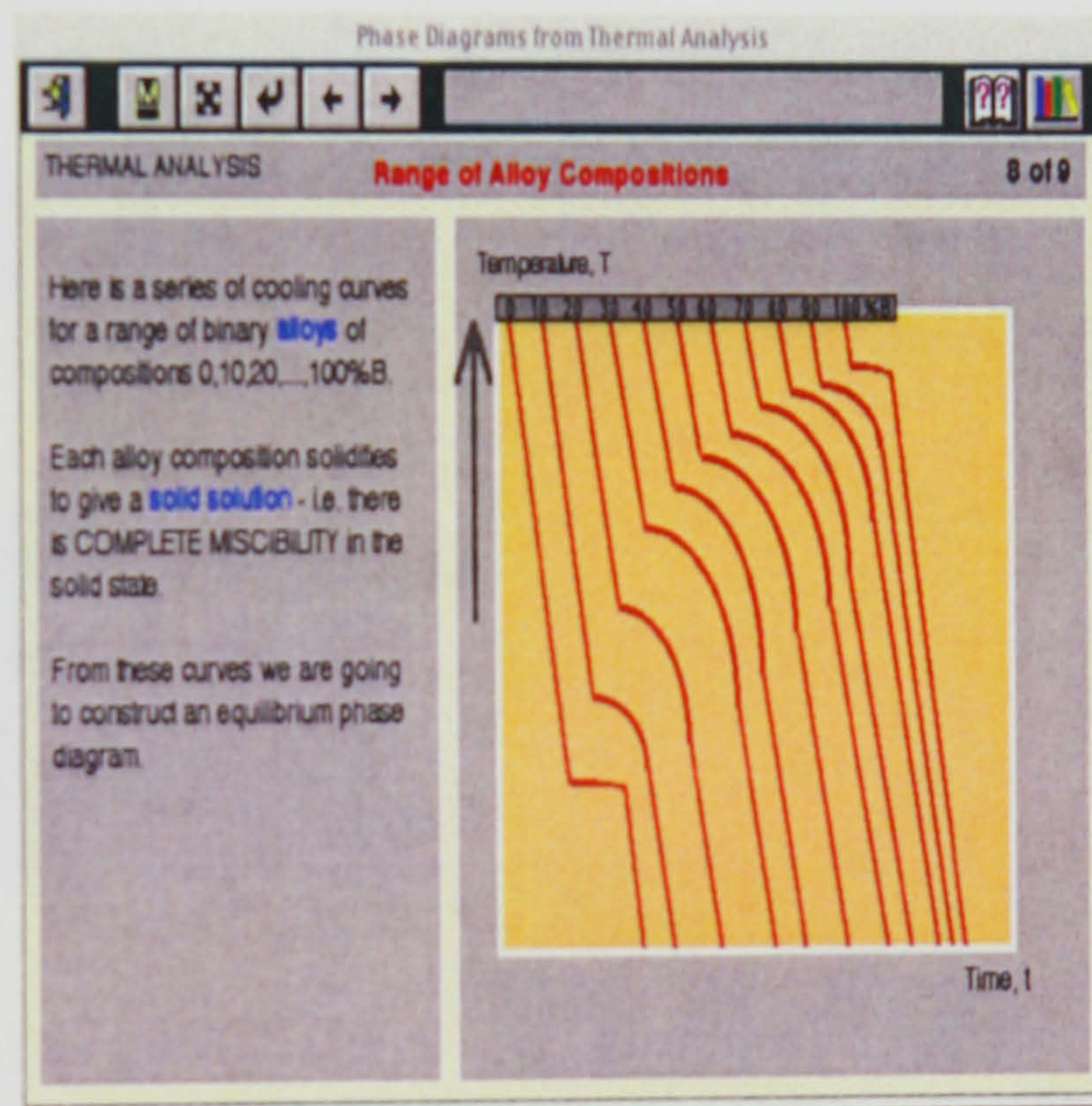


Figure 24 Binary system cooling curves



In Figure 25 the learner is shown the cooling curves and asked to remove the time scale. The result is the phase diagram, representing only temperature and composition axis in Figure 25. This series of screens up to this point are intended to help learners to understand that cooling curves are distinct from phase diagrams.

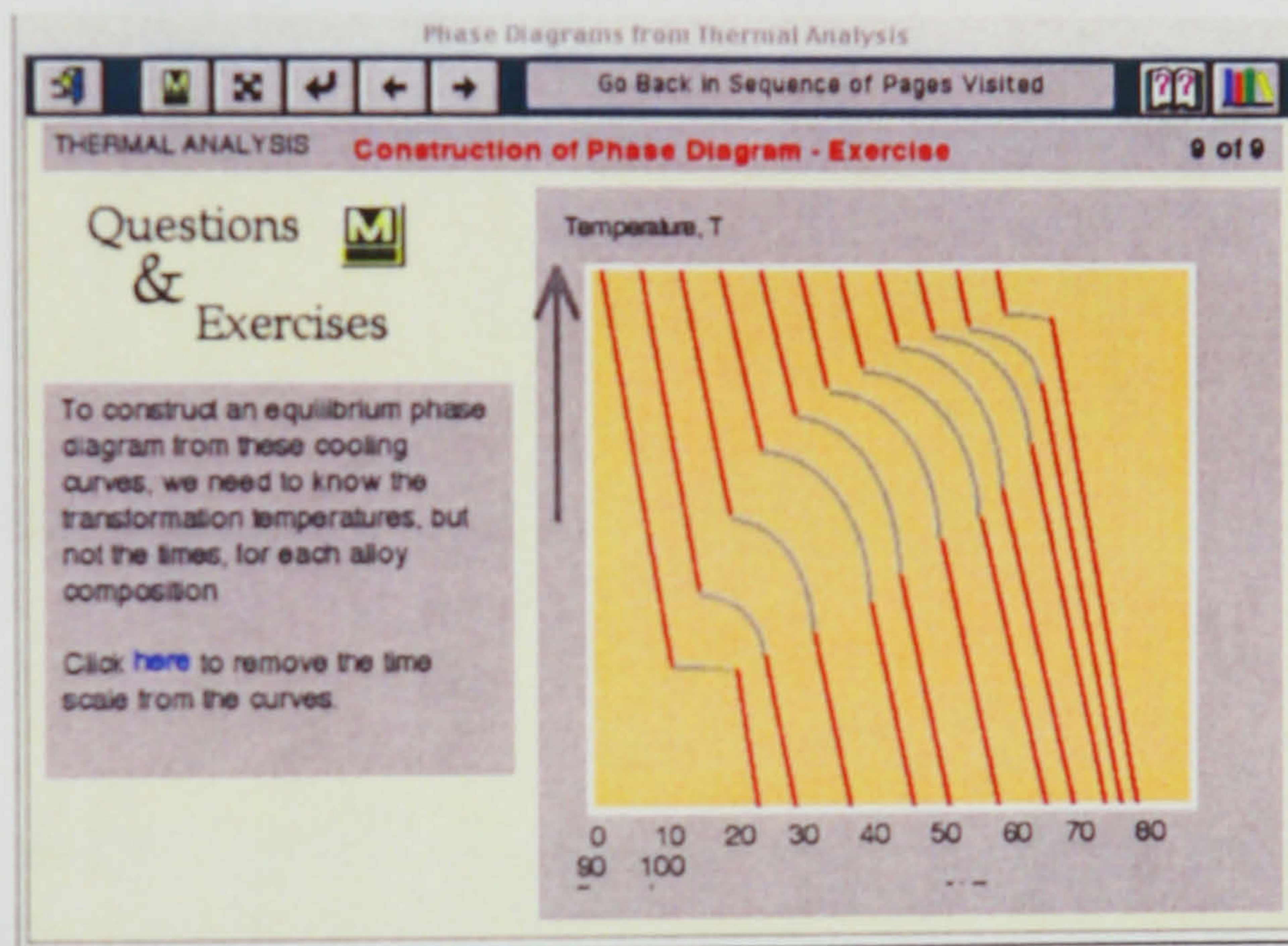


Figure 25 Construction of a phase diagram from cooling curves with time scale



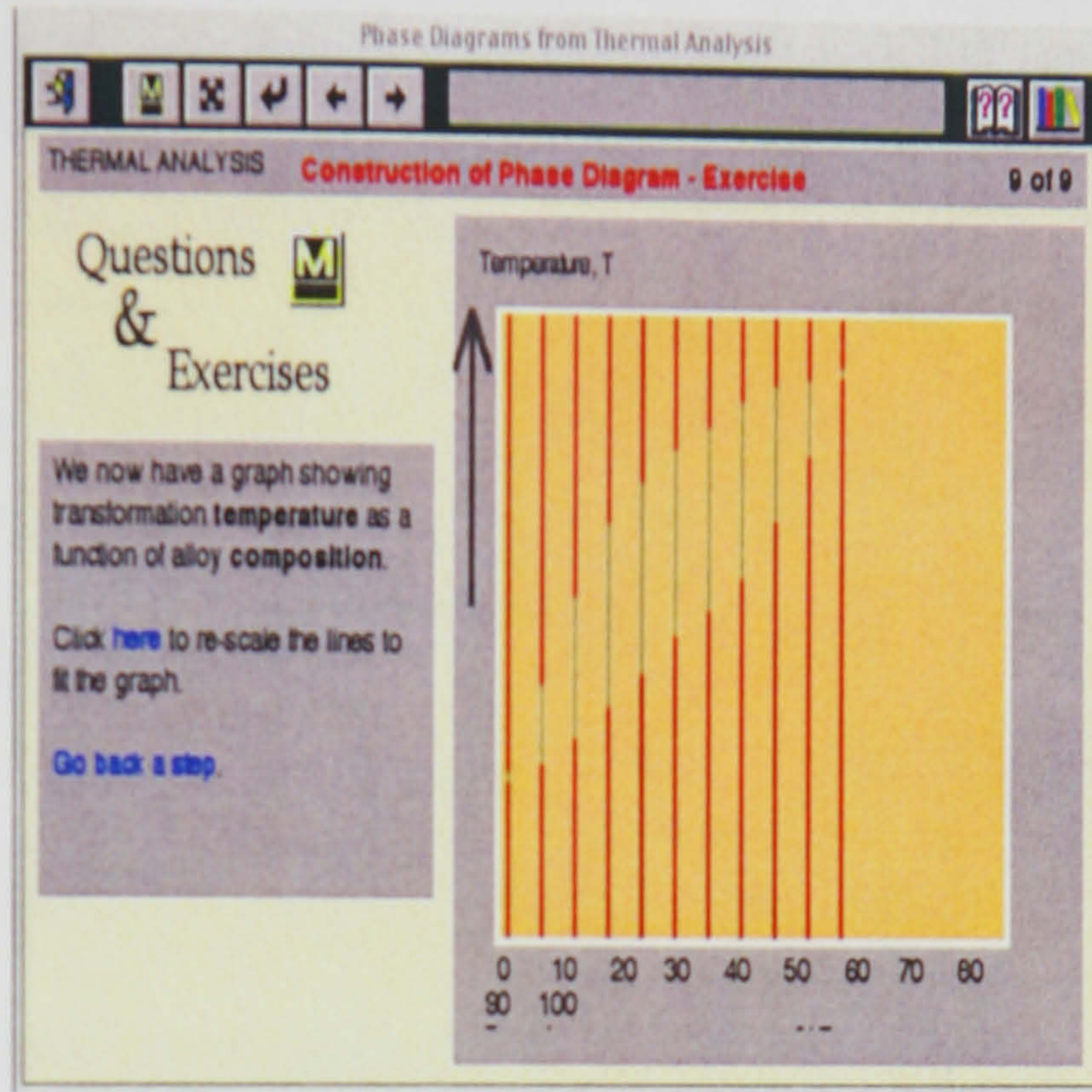


Figure 26 Construction of phase diagrams removing time scale

The summary of the section concludes with statements of objectives the learner should have achieved, and a reiteration of the idea that equilibrium phase diagrams are independent of time. The underlined text indicates terminology that is defined in the glossary. Notice particularly the last line of this screen shot that emphasizes that equilibrium phase diagrams are independent of time.



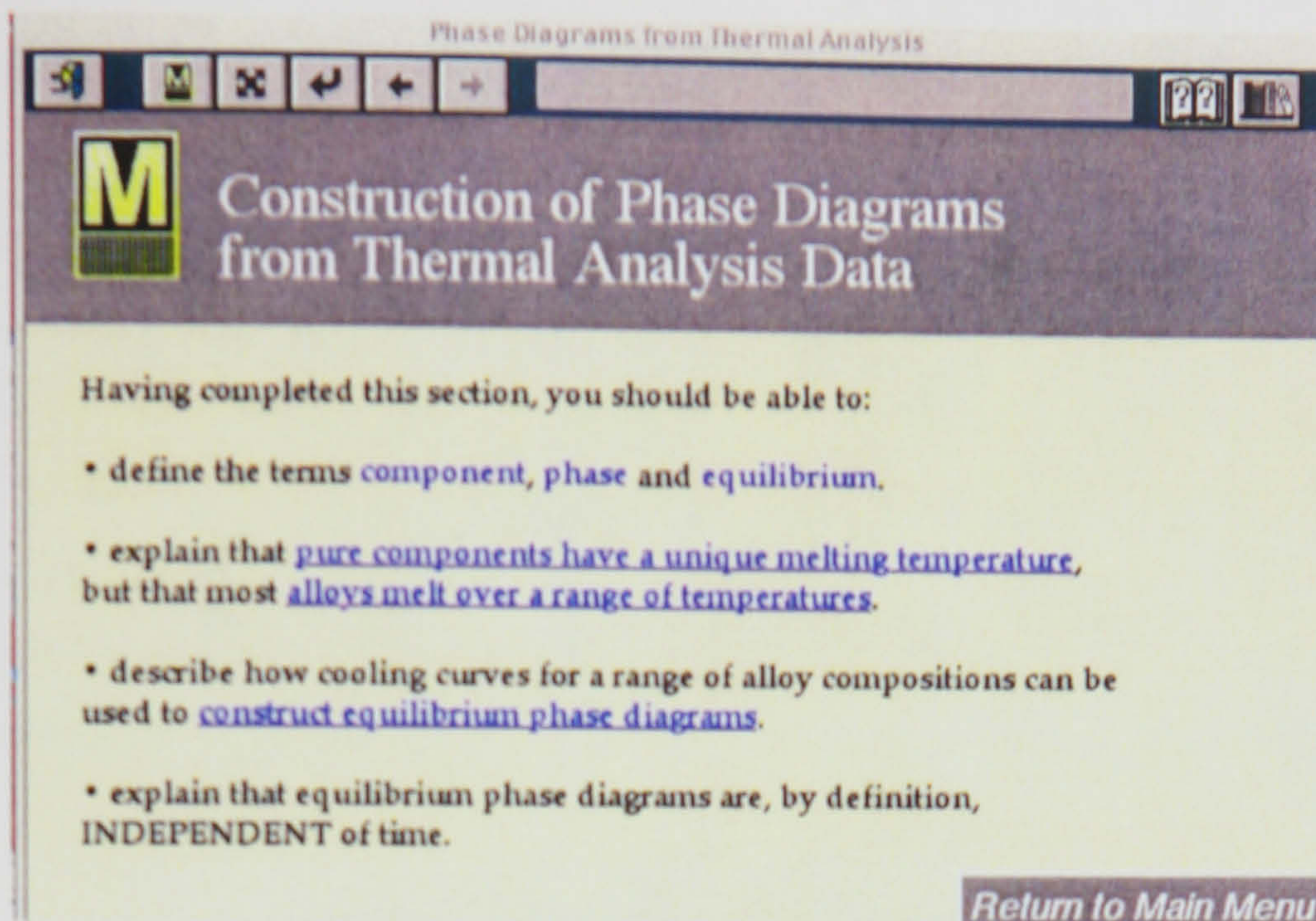


Figure 27 Summary screen for Thermal Analysis section

This series of screens shows how the developer tried to design a strategy to help the learners overcome the misconception that time is represented on a phase diagram. However, the limited explanations provided on these screens may still leave the learner with confusion. A summary that would have brought the explanation together would have been useful, in place of a statement about what they should have learned.

Another design strategy developed on the basis of the phase diagram study was a hyperlink glossary of terms. Recall that the students demonstrated some confusion about terminology associated with phase diagrams, specifically the difference between a phase and a phase region. The developers decided to use what the students were confused about to relate the terms they did not understand. In Chapter 5 we discussed that phenomenographic studies can help us to understand the nature of the confusion between terms in a domain or that students may be attributing more common-sense (everyday meanings) definitions that are not appropriate in the learning context.



We considered a design strategy to help students in this regard by developing conceptually related dictionaries, where terms that are easily confused or terms that have both everyday and scientific or discipline-specific meanings are linked, a distinct advantage when one is designing in an electronic learning environment. The glossary in the Phase Diagrams software provides a comprehensive list of terms. The definition for related terms that were identified as confusing for students include reference or comparison to other terms in the glossary and are hyperlink. For example, the following two entries are for phase and phase region. Notice that in figure 28 the glossary refers the student to compare the definition of phase with phase region. And Figure 29 refers to phase. In the final CD version, these terms are hyperlinked to make it extremely easy for the learner to compare the two.

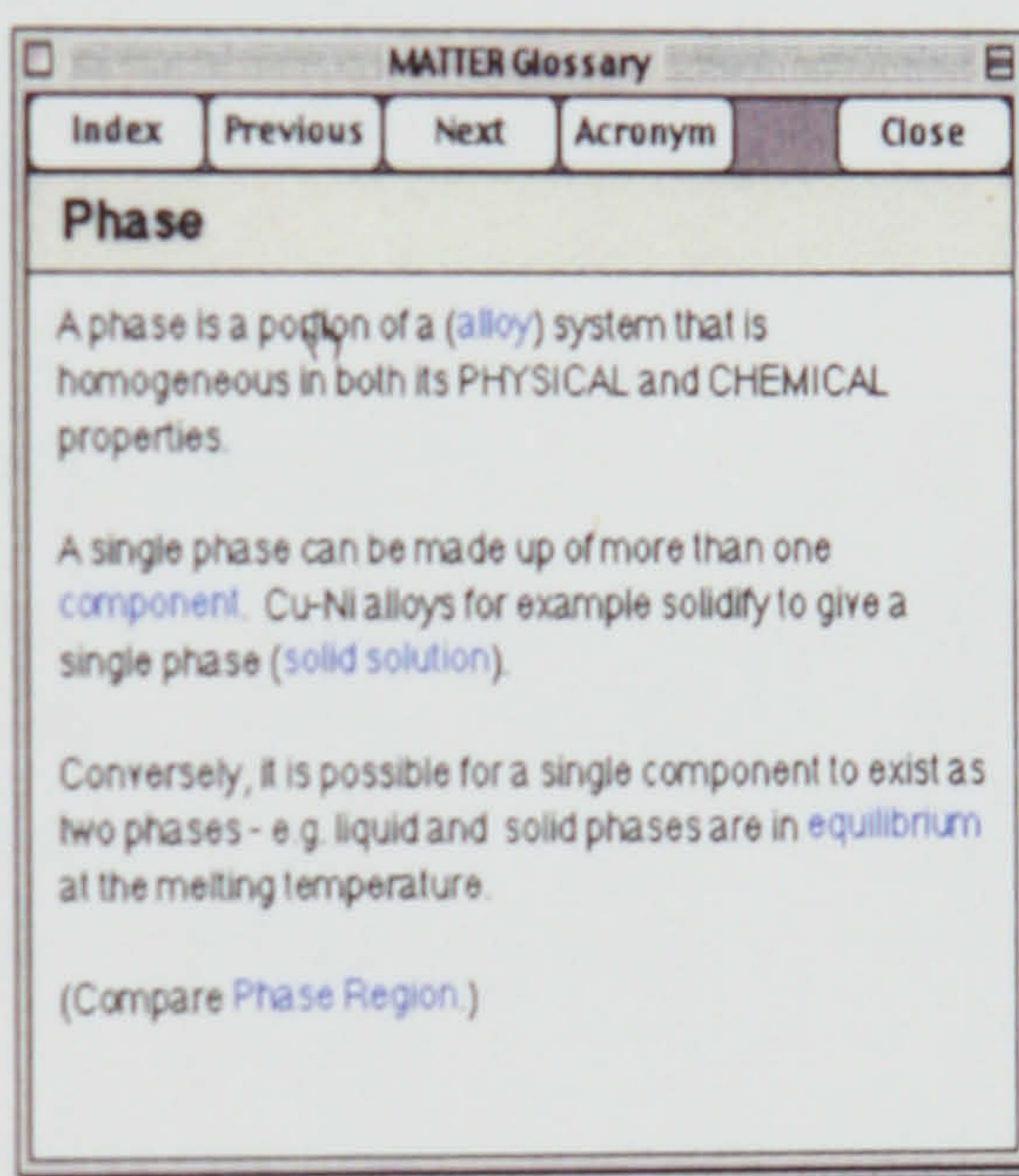


Figure 28 Glossary entry for Phase

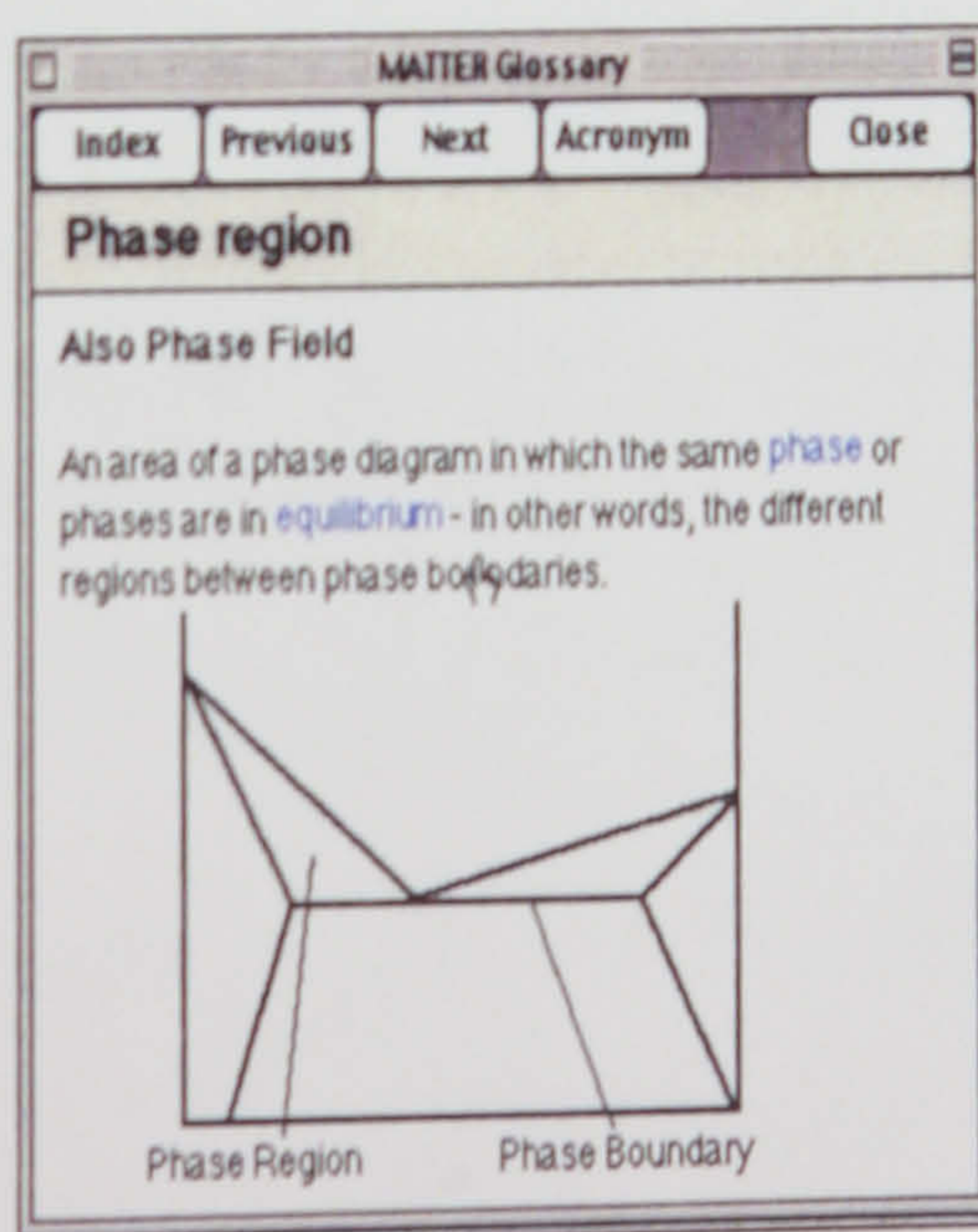


Figure 29 Glossary entry for Phase Region



Time is directly addressed, although the explanation was likely too limited to help learners to understand the relationship. We also saw how the data regarding confusions between phase and phase region led to the development of a glossary that made reference to the precise terms that were confused by students in the phenomenographic study. These strategies were developed as a result of identifying conceptual difficulties students experienced, and through a series of discussions with experts, determining the potential source, or pedagogic errors, that led to the difficulties. The opportunity for the developers was then to design strategies in light of these difficulties.

Recall that this particular prototype module was the first in a series to be developed by a novice designer, who was also a content expert. The study data provided a starting point for this designer. We now turn to the evaluation of the prototype to see whether the results may indicate how successful these strategies were in terms of learning outcomes.

#### **8.4 The Formative Evaluation Study**

Following the development of the prototype module described above, a formative evaluation study was carried out. My role in this study was in to design the methodology and evaluation instruments, and to review the final evaluation report. A second evaluator carried out the collection and analysis of the data, and wrote the final evaluation report.

The intent of the evaluation was twofold; to determine if the software supported improvement in learning outcomes, and to provide a focus for its continued development in order to improve the quality and functionality. The evaluation took place in Imperial College with nine volunteers. The study involved observing pairs of students using the software after they had completed a pre-test interview that included set questions. The student's interactions were tape-recorded during their use of the system. After using the system, students completed a post-test interview. The data available for analysis therefore was both quantitative (test scores) and qualitative (interview transcripts). See Appendix VIII for Pre- and Post Tests.



The overall improvement in test scores from the pre and post-test was 12.2%. This rather small change may be due to the many interface and navigation difficulties students experienced with this early prototype. These kinds of technical problems may interfere with the students' attempts to interact with the software. In particular, Dobson (1994b) discusses the interactive diagrams;

*During the evaluation, students would make incorrect interactions by (i) using the diagram incorrectly e.g. dragging the constitution point up and down instead of left-right, thus revealing faulty models of the diagrams operation. (ii) Would pass by the diagram not realising that it was able to be manipulable, thus revealing problems with the direction to the student and (iii), Would interact with the diagram but would not seem to engage in any thought of the consequence of its behaviour.*

(Ibid, Pg.18)

Clearly, the software required re-design consideration in order to overcome these kinds of problems. See Dobson (1994b) for a detailed list of recommendations.

The qualitative changes from pre- to post-interviews were not categorized or summarized in this report. However, the following excerpts demonstrate that although there were some positive changes in qualitative understanding of the term 'phase', many of the students continued to have difficulty with this concept, particularly in relation to the concept of 'phase region'.

The following responses to the question "what is a phase?" were given on the pre-test interview.

A material can exist in different states which are known as phases. Water can exist in three distinct phases solid, liquid and gas. S3Pre

A phase is a component of a mixture, which is macroscopically distinguishable from another phase S7Pre

A phase is a homogeneous region in a phase diagram S1Pre



A phase is a region on a phase diagram S2Pre.

The above demonstrates the confusion between a phase and a phase region, the same misconception that was identified in the phenomenographic study described earlier in this chapter.

When asked the same question on the post-test, the students made the following responses:

A phase is physically and chemically homogeneous S5,6 and 7Post

A phase is the state at which an element or substance is at a certain temperature and composition whether its liquid, solid or gas phase S4 Post

The above demonstrates that these students are developing a more viable conception of a phase, i.e. it is homogeneous in its chemical and physical properties, and is related to composition and temperature variables.

The formative evaluation study provides further evidence of the persistence of difficulties that were found in the phase diagram study, specifically in the interpretation of phase diagrams. The pre-to post-test average score improvement of 12%, though slight, did provide some evidence that the module provided learning support, despite interface and navigation problems. Scanlon et.al. (1998) discuss the difficulty of establishing whether, or how students learned from a program. Their conclusion is to consider the use of interviews and observation, which was done in this study. It appears that the module indeed helped learners to develop a better understanding of the concept of a phase, as evidenced by the interview transcripts.

## 8.5 Conclusions

This chapter has presented a small study of a representative sample of students who were learning about phase diagrams. The data analysis resulted in 3 categories of difficulties that were presented to a team of experts and developers with the intent to observe how the team would interpret them in the form of design specifications. Formative evaluation of the early prototype suggests that the software provided positive learning experiences for students. The evaluation also demonstrated that there was scope for improving the program based on



the experiences of the learner. Studying the way in which the program did or did not support learning therefore enhanced the re-design process.

We have also seen that it is important to plan for the presentation of the data when involved in a team-based design, and to involve the appropriate stakeholders at various points in the design process. The researcher must understand who will be using the data and how the data will be used. The most important aspect of the communication of the results is to encourage the team to focus on the learner and their experiences. During the workshop presentation of student transcript data, the team discussion was concerned with how it was possible for learners to say such things despite being taught otherwise. This focus on the experience of learning enhanced the expert's understanding of how their teaching was perceived by learners, and motivated them to further explore the source of the students' difficulties.

#### **8.4 Integrating Phenomenographic and Evaluation Data in Design**

The following summary provides a view of the factors involved in integrating the data from the initial phenomenographic study into the alpha prototype, and the integration of the formative evaluation results into the beta prototype.

##### **Data Types**

- **Raw transcripts:** Presented to content expert (lecturer)
- **Categorized excerpts:** Presented to development and management team
- **Design specifications:** Created by development team in response to data input

##### **Communication Methods**

- **Reports:** Summary of student transcripts in written report form. Formative evaluation report.
- **Workshops:** Presentation of categorized excerpts to project team.
- **Inclusion of stakeholder in study:** Lecturer was integral to study design and data interpretation, and became an advocate for the approach with the larger project team

##### **Analysis Method**

- **Individual:** Initial categories developed by evaluator



- **Inclusion of stakeholder:** Lecturer revised categories and placed transcripts into categories
- **Verification by peers:** Project team reviewed and commented on categorization of transcripts

### **Stakeholders**

- **Content expert:**
- **Development team**
- **Management team**
- **Students**

### **Development Stage**

- **Needs Assessment:** Small-scale phase diagram study
- **Design:** Use data from study to develop design specifications
- **Prototype (Alpha) Development:** Develop prototype according to specifications
- **Formative Evaluation of Alpha Prototype:** Collect data on navigation, interface, and learner outcomes
- **Prototype (Beta) Development:** Use data from formative evaluation to re-design prototype
- **Final Product**

This summary of the project progress and input from these specific data sources concerned with student experience is of course not the entire development picture. The management group provided extensive consultation to the developers on what needed to be presented to the students. The developers created an interactive module on phase diagrams from these consultations, and from the data from the studies.

## **8.6 Summary of Design Guidelines**

This chapter has considered how the integration of data from a study of students might be communicated and managed in a project team environment. Based on the former section that described how the developer was able to interpret the results of the study, I have shown that it is possible for phenomenographically-inspired data to inform and improve design decision-making even for a novice developer as in this case. The following new design



guidelines have been generated based on the experience of working in the team environment;

- Analyze any existing test materials, or learner's work for clues as to the kinds of difficulties students' experience with the content.
- Interview at least one content expert/academic to determine if they are confident that they know the kinds of difficulties students experience in one's course. Ask them to articulate at least one case where a student revealed difficulties to them either through formal assessment or class discussions.
- Establish a working relationship with a content expert who can assist in the analysis of student transcripts, and can play the role of advocate for the learner perspective. The researcher may or may not be part of the team for the entire life of the project, and so it is important to identify a particular individual who will maintain the focus on the learner. Ideally, this person (as was the case in the phase diagram project) should be a respected academic in the content area and demonstrate an interest in understanding how to improve teaching and learning.
- Communicate results of the studies in a discursive environment to allow team members to discuss their reactions to the data

The phenomenographically-inspired studies described in this thesis have focused on illuminating knowledge-intensive or knowledge-rich aspects of module-level objectives to be learned. They have focused on key concepts that are fundamental to the student and to their future success in the discipline. The issue of fundamentals is important, as we have seen, that students continue to have ill-formed notions about the discipline in which they are learning, despite formal training, and it is likely that this could prevent future success at some point. For example, it is unlikely that a student who experiences conceptual difficulties with fundamental mathematics concepts will go on to success in higher mathematics. It is also possible that persistent misconceptions of key concepts may contribute to students' lack of engagement and interest with the ideas of a discipline. By studying what students find difficult or confusing, we may go some way in designing



materials and teaching approaches that will help the learner to understand the key ideas and thus experience the satisfaction of achieving success.

The design of learning materials is a complex process that requires an understanding not only of expert view of the content but the students' perspective (and misconceptions) of the content and the gap that exists between these two views. As this chapter has demonstrated, the identification of this gap is the main role to be served by phenomenographic studies in instructional design. The main content expert for this project left before formal data could be gathered on her perceptions of the impact of participating in the study on her teaching. However, after completion of the formative evaluation study, we were surprised that students performed so well on the pre-tests given the difficulties they revealed in the phenomenographic study. The lecturer said that she had integrated what she had learned about the prior conceptions revealed in that study in her classes almost immediately, changing the language she used to explain the basis of phase diagrams, taking care to explain the indices on the representations and how they might confuse the role of time. Not only did this revelation help to explain the good results on the pre-test, but also demonstrate the value of involving motivated university teachers in the process of research.

The following is a summary of the 4-stage design model that includes all the guidelines that have emerged from lessons learned from each of the empirical studies. In addition to the 4-stage model, an overarching management process is presented that occurs throughout the design.

### **Managing the Design Process**

- **Establish a good working relationship with a content expert who can assist in the analysis of student transcripts, and who is sympathetic to the learner perspective.** This is a key factor in the successful integration of the study data in the design process that will have an impact on everything that you do. Initially, the content expert can provide their expertise in the content analysis. The expert then can assist in defining the scope for a study and creating tasks/problems and in analyzing the results. More importantly, because of their credibility in their discipline, their representation of the results of the study to the larger team will be extremely valuable.



- **Communicate Results.** The communication of results involves developing a format that can help others to understand the significance of what the learners have revealed in the study. In many cases, the audience will be unfamiliar with qualitative research methods, and may regard the use of student transcript excerpts as suspect. Visual representations (as were presented in Chapter 6) of the outcome space can be helpful in demonstrating the hierarchical relationship between the categories of description and can be used to show the patterns of movement between the categories. Communication between the designer and the expert and/or team will occur over the course of the design process.



### **Stage One: Expert Analysis**

This is similar to mainstream instructional design task analysis and content analysis. However, the intent in the interaction with the expert in this case includes the determination of the key concepts that will constitute a learner-centred study in the next stage.

- **Carry out an initial expert-based content analysis.** Generate a model set of conceptions on which the design will be based. Along with the process of articulating the model or expert view, the designer gains insight into the expert's experiences of teaching, of strategies that have been successful or have failed, and establishes a relationship with an expert that will be valuable to the later analysis stages of the development process.
- **Analyze existing student work.** Illuminate the perceptions of the expert about areas in which students might be lacking in knowledge. This process involves reviewing examination papers and helping the expert to articulate the kinds of questions we might ask students that would indicate their understanding or misunderstanding of important concepts.
- **Analyze visual representations to ensure that they reflect accurately the conceptual understandings you want the students to learn.** Visual representations need to communicate the concepts that the learner is trying to understand. Collect explanations from the experts in response to queries about what the representations mean from a conceptual point of view and focus on the salient aspects of the representations.
- **Identify technical terms that may be confused with everyday usage (e.g. force in physics).** In consultation with the expert, make a list of all the technical terms in the learning materials you are developing, and discuss how these terms may be confused with everyday usage, for example, force in physics.



## **Stage Two: Learner Analysis**

This stage of the model is concerned with collecting and analyzing data from the learners. It begins with defining tasks that will help reveal the learner's understanding of the key concepts associated with the intended learning materials. It includes the identification and analysis of approaches to learning, interpretation of visual representations and difficulties associated with discipline-specific terminology.

- **Create tasks/problems to study that require an application-level understanding of the material.** Exams do not always provide insight into students' conceptual understanding. The tasks or problems used in phenomenographic studies must go beyond simple facts or definitions, and require students to provide explanations of core or key concepts. The learner needs to articulate either through verbal protocols, or through some kind of artifact (i.e. maps, phase diagrams) that they can explain the conceptual underpinnings of an idea.
- **Carry out a study of a representative sample of learners.** Select a representative sample of students in cooperation with the context expert. The selection can be based on a range of abilities as demonstrated on exam or coursework, or as an option for students to volunteer without influence of an expert. The size of the sample can vary from 5 to 20, depending on the amount of time and resources available.
- **Analyze the transcripts or artifacts and develop emergent categories of difficulties** First, develop a few broad categories that appropriately describe the students' work. Then consult with the content expert to develop the categories. This will usually result in a larger number of more narrowly defined categories. At this point, decide whether the categories you have are sufficient in explaining the difficulties revealed in the study. If not, you may need to carry out a more in-depth analysis by developing architecture of variation that shows the logical structure between the categories and the potential points where barriers exist.



- **Look for evidence of deep and surface approaches to learning.** Look for evidence of deep or surface approaches in the explanations that students provide. Surface approaches will tend to focus on discrete elements of a problem. Deep approaches will tend to focus on integrating elements of a task or problem. Describe the approach and categorize the transcripts.
- **Analyze difficulties with visual representations.** Analyze the role that the visual representation plays in the explanations or problem-solving strategies in which the learner engages. Does the learner understand the purpose of the representation, and how it is to be interpreted?
- **Analyze difficulties with discipline-specific terminology.** Look for evidence that students are confusing terminology within the topic area (such as phase vs. phase diagram) and scientific or technical terms with everyday usage, such as valley vs. syncline.
- **Determine sources of pedagogic errors for existing teaching materials.** Look for three broad categories of pedagogic errors: Sequencing (order of presentation), Representations (the use of visual materials), and Mnemonics (the use of rules for remembering). Determine if any of the strategies used in these categories may cause the learner to engage in surface approaches to learning. This will involve discussions with experts that focus on mutual reflection on the interview evidence.

### **Stage Three: Design and Development**

This stage of the model involves the integration of the expert and learner analysis data in order to design and develop the learning materials. At this point, one can proceed on her own or provide guidance to another designer and allow them to analyze the transcripts further.

- **Generate objectives based on the categories of description.** Once the transcripts have been analysed and allocated to categories of description, formulate an objective that had as its focus the problems identified for each category. The



objectives should be written in such a way that one could clearly see that having been achieved by the student, difficulty described in the category would overcome.

- **Generate assessment items based on the objectives** The design of assessment items follows logically from the development of objectives, and the two should have a coherent relationship, with assessment items becoming the driving force for the development of learning activities in the design process Generate an assessment item that encourages active engagement of the learner with the content part of the learner for each objective.
- **Generate learning activities that will support the opportunity to successfully achieve the assessment items.** Design learning activities to help the learner to interact with the content, and to compare their understanding with the model understanding This will involve a number of other design elements including development of feedback and visual representations. Additional aspects of a learning activity include helping the learner to situate each activity within a larger context. Provide links back to previous activities through summaries or synthesis, and remind the learner of how the current activity relates to the overall goal of the learning package.
- **Develop feedback for students based on the transcripts from the study and expert explanations provided throughout the design process.** Use the student transcripts to establish the kinds of explanations that the learning activities will need to provide in order to overcome particular conceptual difficulties. These explanations can be developed in consultation with the content expert, or constructed based on previous interviews with the content expert regarding the domain. Always provide the model answer and solution that the student can use to self-assess their answers and solution.
- **Sequence the learning activities based on the level of difficulty as represented by the assessment items.** Establish the level of difficulty by considering the concepts students did not easily understand. In most cases, the more difficult concepts will be demonstrated in the transcripts by confusion or inability to



articulate any kind of coherent explanation. Further consultation with the content expert may also provide assistance in establishing the relative difficulty levels.

- **Develop strategies for overcoming difficulties with the use of technical terms**  
Generate comparative explanations of the scientific and everyday usage. Additionally, develop a glossary that links terms that are confused (i.e. phase and phase region) within a domain.
- **Generate visual representations** Where possible, generate dynamic, interactive representations that allow the learner to manipulate them, with the additional support of conceptual explanations. Ensure that the representations are accompanied by examples and explanations that focus the learner on processes of interpretation.

#### **Stage Four: Evaluation**

This stage of the model is intended to serve as a reflective activity.

- **Evaluate each learning activity on the basis of the kind of learning approach that you wish to promote.** Consider how each learning activity is interpreted by the learner in terms of the demands of the task. Does the learner need to carry out an interpretive approach to solve the task, or is the task designed to allow the learner to apply a mechanistic approach?
- **Evaluate the level of abstraction of the design.** One of the potential difficulties in integrating phenomenographic data in design is that the designer will focus more on the specific difficulties than on the larger course objectives. This can in part be overcome in the learner analysis phase, where the themes that are constructed in the analysis of transcripts form a set of categories of description that relate to high level objectives. For example, the simple confusion of two terms may be indicative of more general (or abstract) difficulties. Ensure that the main concepts and principles are part of the explanations and feedback provided to learners in order to ensure that the appropriate level of concept abstraction and generality are addressed.
- **Use the Conversational Framework to ensure the learning interactions are sufficient.** This teaching-learning model provides a way of evaluating how well the



design of the learning environment supports the necessary interactions between the learner and the teacher (or teaching system).

- **Evaluate Effectiveness of the Materials.** Carry out a small-scale formative evaluation study to investigate how well the designed materials assist the learner in overcoming the conceptual difficulties identified in the analysis stage.

The above guidelines are intended to assist the designer or teacher to formally identify and analyze the difficulties that learners experience with content in order to improve teaching and learning. As additional design efforts are carried out, the guidelines will be extended and refined. In the next and final chapter, a summary of the main findings and research outcomes of the thesis are presented. The implications for instructional design and teaching are discussed, and future research is outlined.



## **Chapter 9            Discussion and Conclusions**

**This thesis began by presenting the view that analytical instructional design theories focus on general principles of learning, and represent content to be learned according to logical conceptual, procedural or theoretical structures based on an expert's view of a topic. Two case studies have demonstrated that learners do not acquire knowledge in a predictable sequence, nor do the strategies used in developing materials from an expert perspective always result in learning. This thesis has described how phenomenographically inspired instructional design may be accomplished**

**In working with experts in the two cases presented in this thesis I have discovered that content experts or instructors have difficulty in determining what students find difficult and why, and more importantly, how to design learning experiences that will help overcome the problems. The potential solution to this problem appears to be to engage experts in discussions focused on the difficulties learners experience based on evidence collected in interviews that constitute emergent categories of difficulties.**

**The two cases presented in the thesis have demonstrated how input from learner-centred studies is realized in the design of learning materials. In the case of geological mapping, the research and development process was as follows;**

- A study of students' understanding of how to interpret a simple problem map**
- The design and development of text-based learning materials**
- Two evaluations of the effectiveness of the learning materials**
- The development of design guidelines as a result of the above activities and lessons learned.**



The second case in phase diagrams in metallurgy offered a different design context, where a team of stakeholders was involved in the Research and Development process, and the following studies;

- A study of students' understanding of phase diagrams
- Facilitation of expert's view of sources of pedagogic errors
- The design and development of a computer-based module
- The evaluation of the effectiveness of the module
- The further refinement of the design guidelines (from above) to include team-based design considerations.

This chapter begins with a summary of the key findings followed by a discussion of the implications for design of learning material for teaching and instructional design. This is followed by a discussion of the lessons learned from carrying out this kind of research that identifies some of the challenges that were met. A brief discussion of the role for phenomenographic studies in constructivism is presented, and the chapter ends with a description of future research.

## **9.1 The Main Findings**

The intent of the work presented in this thesis has been to investigate the role for phenomenographic studies in instructional design, and to determine how the data from such studies might inform instructional design practice. The first key finding is that **studies of learners' conceptions and approaches to learning yield valuable data that can be used to design effective learning materials.** The integration of a phenomenographic approach in design has been shown to have a positive effect on learning outcomes in the cases presented in geological mapping and phase diagrams. The direct and indirect impact of phenomenographic studies was demonstrated through the articulation of the design process. I have shown the interview data can be used directly in the development of particular design elements (i.e., objectives, feedback) the most important element is the development of objectives, as this drives the entire design process. Setting the objectives using student-centred data may preclude the development of misconceptions by focusing on the concepts that students find most difficult to understand.



The second key finding is that participating in **phenomenographic studies can enhance the reflective practices of instructional designers**. I have shown that the experience of carrying out phenomenographic studies influences the focus of the design process. Designers who carry out or even just use the results of these studies focus on trying to figure out why students demonstrate the difficulties revealed, and subsequently on developing interventions that will help the learner to develop a more appropriate conception. This is as a result of engaging with the learners and the content experts in an effort to come to understand the kinds of obstacles they both face in terms of content and design.

The third key finding related to the above is **that there is a gap between what students need, and what experts think they need**. In both studies, lecturers were surprised that learners did not learn what they had believed they had taught. In some of my discussions with the experts, there was a tendency to attribute this mismatch to the lack of prior knowledge of the students. Lecturers had assumed that learners had mastered particular concepts. They had clearly not established the gap between what the learners knew and what they wanted to teach. One lecturer attributed the source of the mismatch to the lack of study skills. This appears to be a promising factor to continue to explore. Study skills inventories **might be used as a way of initially selecting participants, as was done in the phase diagrams study, or as a way of evaluating the effectiveness of new design strategies on students' study approaches**. However, the solution for overcoming the gap between the what students need and what experts think they need resides with the design of teaching materials, not with improving the study skills of individual learners.

Related to the above, the fourth key finding is that **data derived from phenomenographic studies provide qualitatively different data than data derived from experts**. The expert has a sophisticated model of the domain to be taught, and is able explain the relationship between complex concepts within a domain. However, the expert may have limited understanding of alternative ways that a domain is understood. Therefore, two types of content analysis are required in order to carry out a comprehensive instructional design effort: **expert-based content analysis and phenomenographic analysis of learners' conceptions**.



## **9.2 Contributions**

The contributions in this thesis are to two main research areas; Instructional Design Practice and Research, Geology Teaching and Learning and Phenomenography.

### **Contributions to Instructional Design Practice and Research**

The main contribution of this thesis is research-based development of design guidelines that have been generated. The guidelines were initially presented in Chapter 4 and subsequently extended as the research progressed, and further implications for design emerged as part of an ongoing process of coming to understand the utility and value of data derived from the studies as presented in this thesis. The final result is an eclectic model of instructional development that draws from the strengths of the field of instructional design in articulating the inputs and outputs in decision-making, from Laurillard's conversational model of teaching and learning that specifies the interactions necessary to take place between and learner and teacher, and from a reflection on my experience of gaining insight into the learner's perspective. These guidelines represent a refinement of those presented in Chapter 5 that guided the design of the learning materials based on the lessons learned in the two evaluation studies. They also include items that were added as a result of involvement in the phase diagram development team effort.

The guidelines are structured according to 4 main stages; Expert Analysis, Learner Analysis, Design and Development, and Evaluation. The major contribution to instructional design practice is the addition of the Learner Analysis Stage, one that is frequently given little attention in both mainstream analytical models and in more contemporary constructivist models (Hannafin, 1999b). One of the important aspects of the model and guidelines is the links between the stages. If one were to only consider the stages, the model would appear similar to any instructional design model. However, it is the nature of the analysis within each of the stages, and the kinds of data input and output that are being generated that distinguish this approach to design from others.

#### **Stage One: Expert Analysis**

This is similar to mainstream instructional design task analysis and content analysis. However, the intent in the interaction with the expert in this case includes the determination of the key concepts that will constitute a learner-centred study in the next stage. The designer is analyzing the expert perspective in preparation for carrying out the next stage of



analysis. The focus on analysis of technical terminology that may give students difficulty pre-supposes that one may find conceptual difficulties.

### **Stage Two: Learner Analysis**

This stage of the model is concerned with collecting and analyzing data from the learners. The input is the expert account, and the expert's interpretation of potential difficulties the learners may be experiencing. The output is a description of difficulties as constructed from a partial analysis or an outcome space as constructed from a full phenomenographic analysis.

### **Stage Three: Design and Development**

This stage of the model involves the integration of the expert and learner analysis data in order to design and develop the learning materials. The guidelines provide pointers on how data from each of the previous stages are integrated in particular design elements.

### **Stage Four: Evaluation**

Evaluation in this model is a reflective activity to ensure the quality of the design. Laurillard's Conversational Framework is suggested as a model for evaluating the teaching and learning interactions of the materials developed.

The above guidelines are intended to assist the designer or teacher to formally identify and analyze the difficulties that learners experience with content in order to improve teaching and learning. As additional design efforts are carried out, the guidelines will be extended and refined.

### **Contribution to Geology Teaching and Learning**

The main contribution of the research in this thesis to geology teaching and learning is the development of the outcome space and architecture of variation for geological mapping. The outcome space is a particularly interesting framework that geology teachers and researchers may find useful in further understanding how to go about teaching geological mapping, and potentially where to place the teaching of geological mapping within a  
g e o l o g y    c u r r i c u l u m .



Based on the outcome space, there is a need to ensure that students clearly understand the differences and relationship between topographic and geological features, the role of continuous and discrete-time related processes on the *appearance* of geological structures. In terms of the placement of geological mapping within a geology curriculum, the outcome space provides some evidence that the early introduction of mapping may be inappropriate and that students require more knowledge of geological processes in order to successfully interpret a geological map.

In addition to the outcome space, the identification of surface and deep approaches to geological mapping points to potential improvements in teaching and design. We were able to show that students who applied a deep approach were successful in interpreting a map and in finding evidence from the map to support a 'story' about both discrete and continuous geological and surface processes (topographic processes). This result indicates that future teaching and design of geological mapping should include encouragement of a deep approach.

### **Contribution to Phenomenography**

The principle contribution to phenomenography has been to demonstrate the utility of adapting the phenomenographic analysis method to a pragmatic design context. In the two case studies presented, the analysis of the data involved developing Categories of Difficulties, a new outcome not previously identified in the literature. In contrast to the traditional analysis outcome in phenomenographic study, the Outcome Space, the categories of difficulties do not have clearly articulated logical relations between them. However, the thesis has demonstrated that they are sufficient to inform design decisions, and are useful as vehicles for discussions with experts to illustrate the way in which learners explain their conceptions of the material they are trying to learn.

### **9.3 Lessons Learned**

The experience of carrying out the research in this thesis has been conducted in the spirit of an action research process (Kember, 2000). The initial pilot study provided some grounding in the application of a phenomenographic method that led to reasonably precise statements about the needs of students. The development of the geological learning materials involved



engaging with the subject experts, communicating the results of phenomenographic studies make sense to non-phenomenographers. This management of the communication and the establishment of cooperative relationships in design are crucial, particularly when introducing innovation.

### **Approach to analyzing phenomenographic data**

A pragmatic approach to analyzing phenomenographic data can be useful in design, both for an individual designer and for a team. The learner analysis studies in this thesis have resulted in the development of categories of difficulties, an adaptation of the classical phenomenographic analysis method. It is not clear how much more value the design effort will gain from a more sophisticated phenomenographic analysis resulting in an outcome space, showing the architecture of variation that illustrates the relationship between conceptual categories. There are more lessons to be learned about the analysis methods that help illuminate the experience of the learner. I have recently become aware of the work of Gurwitsch (1964) who advocates a precise method of qualitative analysis that seeks to identify the point in a transcript where a learner shifts focus in themes. This method helps the analysis to reveal the themes, and to identify the shifts in focus. This approach may be useful in considering the variation in the foci at different points in the themes, which may provide some support to the analysis of phenomenographic interview data.

### **Domains studied**

The domains (geology and metallurgy) studied in this thesis shared two main similarities. They were conceptually complex and difficult, and required the ability to interpret visual representations. These two aspects made them interesting from a teaching and learning perspective as the complexity and difficulty experienced by students provided rich data to interpret, and the potential teaching strategies that might be developed were only limited by the design resources and creative thinking available. We have discussed elsewhere that the instructional designer may have certain advantages in formulating and conducting phenomenographic studies, as they are learners themselves and can sometimes usefully ask the right kind of naïve questions. However, given that a phenomenographic approach is most appropriate for complex material, there are two approaches that would be more effective in future efforts. The first is to ensure that domain experts are key members involved in every stage of the process. The second is to train domain experts in the



phenomenographic methodology and have them carry out their own studies that would then be communicated to an instructional designer.

### **The role of visual representations**

There is much more research to be done in understanding the role for visual representations in learning. This thesis identified and described the difficulties students had with interpreting visual representations and how this contributed to misconceptions. I attempted to build simple visual representations in the teaching materials that showed some success. However, the scope of this thesis has not focused on this issue in a comprehensive way.

### **Study sample sizes and level of analysis**

The size of the sample as well as the level of analysis for a phenomenographic study can vary, depending on the availability of resources and the intent of the study. In geological mapping, 12 students were interviewed, using a well-defined task. The students were identified by the course tutor as experiencing difficulties, so that they represented mainly the misconceptions and not the ideal conceptions. In the phase diagrams study, a very small sample of 5 students were selected by the lecturer based on their representation of a range of abilities as evidenced by exams, coursework results and a study skills inventory score. Both cases yielded good data. However, there are other ways in which a sample might be selected, and other factors that may need to be considered that were not specifically addressed by this thesis that may be of future interest; the age and sex of the participants, their conceptions of learning, and their perceptions of the demands of the course. This data may prove valuable in future studies that could broaden our understanding of how to design learning materials taking into account sociological aspects of learning.

The variation in the level of analysis of the outcome space in phenomenographic studies has been a topic of interest in this thesis. The pilot study revealed categories of difficulty, and the re-analysis of the data later resulted in a more elaborated outcome space. The process of creating the outcome space provided more precise understanding of the path of learning and how learners might meet barriers to learning. The phase diagram study resulted in categories of difficulties based on a partial analysis of the interview data, and was shown to be helpful in design decisions. The level of analysis then must be determined in response to the demands of the design context and the availability of resources. A partial



analysis that identifies the main categories of difficulties is sufficient for designing materials.

### **Perspective on design**

The most important lesson learned has been the shift in my perspective on the design enterprise from one of specifying and organizing expert content to specifying learner experience. The complexity of the teaching and learning process demands that practitioners engage in reflective practice of this kind in order to come to understand their own conceptions of design as a vital part of evolving as a professional.

## **9.4 Implications for Teaching Practice**

Many authors have considered the implications of phenomenographic analysis for teaching (Ramsden, 1988; Laurillard, 1993; West, Lybeck & Marton, 1992; Prosser & Trigwell, 1999). Ramsden (1988) argues that;

*...teachers must learn about what students 'know' and apply what they discover to improving their teaching.*

(Ibid. Pg. 21)

In the geological mapping study we examined the gap between the academics' understanding of the nature of students' difficulties with a particular task and the reality of student difficulties that a phenomenographic analysis can reveal. Recall that one of the geology tutors who served as a judge marking the pre and post-tests in Chapter 6 made numerous comments that suggested that they were frustrated, surprised and puzzled by the lack of ability of students to visualize in 3D, and to engage in thought experiments about how geological areas were formed over time. However, the second judge who was more involved in the study was able to reflect on how the results of the study had implications for her teaching. These were;

*The lack of connection students makes between the rule and the concepts. This is a block to progress.*



*The rules need to be understood if they are to be applied effectively; they can't be applied unless the student is confident that they are applying the right rule to the right situation.*

*When an exercise gives a student a strategy to progress with a task, this needs reinforcing with more practice before continuing.*

*Students need to understand the rules before they can remember them.*

These points demonstrate the value in raising the awareness of university teachers about the prior conceptions their students bring to learning and the continuing difficulties they experience as they are in the process of learning. However, raising awareness may not be sufficient in helping teachers to design teaching strategies that will encourage the development of correct conceptions of a topic.

In the phase diagram study, I reported on the important role played by the lecturer who was interested in ways of improving teaching and learning. The lecturer told me that she had integrated what she had learned about the prior conceptions revealed in that study in her classes almost immediately, changing the language she used to explain the basis of phase diagrams, taking care to explain the indices on the representations and how they might confuse the role of time. This demonstrates the value of involving motivated university teachers in the process of research of this kind and that the phenomenographic method can have an important impact on teaching. Institutions that would hire and support researchers dedicated to supporting these kinds of studies could improve the quality of teaching and learning.

Prosser and Trigwell (1999) provide a summary of why phenomenographic studies are of value to improving teaching practice;

- *To provide relevance to the learning by focusing the students' awareness on the conceptual aims and the learning demands of the subject. Through participating in activities that demonstrate the limitations of their understanding of the content matter and learning itself, the students can be made aware of the need to apply learning approaches which lead to a more complete understanding of the content;*



- *To promote awareness in the students of the different ways they, and their fellow students, conceptualize the subject matter and their learning. The development of more complete conceptions can be encouraged through contemplation of this variation;*
- *To allow the lecturer to become aware of the way students conceive of the subject matter and of their learning, as a precursor to providing teaching approaches designed to improve understanding.*

*(Ibid. Pg.43)*

The first two bullet points above focus on developing awareness in the learner about their own approaches to learning and their own conceptions of the content. These are speculative strategies for learning that are still to be tested. However, the last bullet point focuses on the lecturer becoming aware of the different ways in which learners experience subject matter. In both case studies presented in this thesis, the emphasis has been on precluding difficulties with design strategies by carrying out a learner analysis method inspired by phenomenography and positive results of engaging lecturers in these studies have been demonstrated.

The question is how teachers or lecturers might go about integrating phenomenographic studies in their teaching. This thesis has demonstrated that the following support would be required:

- **defining the nature of a study**
- **helping the lecturer to determine the level of abstraction of the kinds of questions or tasks to put forward to their students,**
- **analyzing the data, and**
- **designing assessment that would test how well these activities improved learning.**

There can be some resistance by lecturers to understanding the nature of their students' difficulties, and to creating strategies that would help them to overcome them. Participation in research studies of this kind have been shown to be valuable to the practice of teaching, on the basis of the data presented in this thesis. However, teachers require further support. The defining factors for successful integration of the study results into a teaching strategy are (i) the level of involvement of the academic, and (ii) the motivation of the academic.



The motivation of the academic is clearly important. An academic who is genuinely interested in improving teaching and learning is likely to learn something from the experience of participating in such a study, and be willing to reflect on their own experiences in a way that will lead to considerations for designing strategies for improving the experiences for their learners. Similarly, the level of involvement of the lecturer has an impact on their ability to take on board the implications of the study results. In the geology case, one of the lecturers who participated in the study was able to integrate the results in her teaching of a tutorial by relating the misconceptions revealed in the study directly to a particular problem map. In the phase diagram study, the lecturer involved readily took on board the results and integrated them into her lectures, and the developer was able to develop design specifications.

How then might lecturers who are willing and interested in such activities be supported? Bowden and Marton (1998) suggest a number of steps that might be taken in order to improve learning in a university. They propose to establish 'knowledge formation' centres and encourage departments to open their doctoral studies for specialization on knowledge formation within their discipline or domain. These doctoral students become the experts in knowledge formation that can guide the research within each domain, with support from the central group. There are two main aspects of their proposal that can be supported by the research presented in this thesis. The first is the active participation of a domain expert in the study of students' experience. The second is that a domain expert who is a credible member of their own discipline is able to more easily promote the learner's perspective than outside education experts. An additional aspect that would strengthen this proposal would be the inclusion of what has been researched in this thesis; a role for an education designer who is able to problematize the learning situation, design and implement a phenomenographically-inspired study, and facilitate discussions with teachers and designers who enter in to an evidence-based, second-order perspective discussion on their students' understanding and learning

And as shown in this thesis, an effective way to influence teaching practice is to have the academic as a participant in the study and design process. This notion is in line with current thinking about action learning and action research (McGill & Beaty, 1995; Kember, 2000) where the emphasis is placed on active participation of practitioners in projects aimed at improving teaching and learning.



## **9.5 Implications for Constructivist Approaches to Instructional Design**

One of the main outcomes of this thesis is an eclectic set of design guidelines has been developed that draw from a variety of theoretical perspectives. Eclectic approaches to design have been criticized by proponents of constructivism (Molenda, 1998; Stone & Goodyear, 1995). Jonassen (1990) argues that a constructivist epistemology leads the practitioner to design learning strategies and environments that will promote constructivist learning. Jonassen (2000) contends that constructivist learning environments are;

*....case-project-, or problem-based environments that engage learners in articulating, solving, and reflecting on their solutions of a problem or project space, including the representation of the problem, descriptions of the context in which the problem occurs, and the ability to manipulate and test various solutions to the problem.*

(Ibid, Pg. 125)

However, even if a designer believes that learning is constructed and situated (for individuals or as part of a community), the implications for design fall short of guidance. The process of establishing an instructional approach for learning for a designer who believes in a transmission model of teaching may lead to the decision that problem-based learning suits a particular situation for a particular group of students given a particular goal. One does not have to hold a constructivist epistemology to design learning environments that constructivists may claim encourage constructivist learning.

Bowden and Marton (1998) argue that advocates of problem-based learning are focused exclusively on the method, and therefore may miss the opportunity to design according to learner needs in consideration of a particular context and goal. They conclude;

*Better, we would argue, to begin with student learning, to analyze the principles of learning and then to draw conclusions about what kind of learning environment and what kinds of learning experience will assist students to learn in the way intended. Only then should we design what we call teaching methods so as to provide those environments and experiences.*

(Ibid.Pg. 150)



This thesis concurs with the quote above and provides a pragmatic response in the form of the guidelines for design. These guidelines focus on the analysis of the experience of the learner and may inform any design effort. In the case of problem-based learning, the data may be useful in constructing tasks that are consistent with the difficulties revealed by students. The data may also reveal deep and surface approaches to learning that could be used in developing problem-based curriculum around hypothesis development and evidence gathering.

## **9.6 Future Work**

There are many opportunities for further research as a result of this thesis. Outstanding questions include;

- How will instructional designers apply the design guidelines?
- How can we identify and pre-empt pedagogic error?
- What role can phenomenographic studies play in improving assessment?

Three research foci are now described that would go some way in answering the above questions.

### **Using the Guidelines in Instructional Design**

This thesis has argued that instructional design practice can be improved through collecting and analyzing data on the perspectives of the learner. Future research will seek to further investigate the utility of the methodology for the practice of instructional design and to extend and refine the guidelines for design.

Professional instructional designers will be recruited to participate in the study that will aim to describe their experiences and their decisions within the context of an authentic instructional design effort. Each designer will be given the task of developing a unit for teaching a particular topic within one course. The research will focus on the designer's experience, any shifts in their perspectives on how they will design in future, and their recommendations for ways in which the guidelines may be extended and improved.



### **Identifying sources of pedagogic error.**

In this thesis, the idea of pedagogic error was considered as a factor in the design process. In the geological mapping study, three categories of error were identified (Sequencing, Representations and Mnemonics) and need to be further understood and expanded in order to better design for learning. The intent is to understand how to pre-empt misconceptions by identifying teaching and design practices that may hinder the correct processing of material. Recall that the explanations for most sources of pedagogic error were centred on the students' application of surface approaches to learning. If we further our understanding of how to identify and pre-empt surface approaches to learning (when surface approaches are not the intent), we will go some way in assisting designers and teachers in helping learners to avoid processing errors that lead to poor results.

The intent will be to extend the number of categories outlined in the thesis by further investigating two contexts: a traditional classroom and a distributed learning environment. The scope for the study will be a full course, and will involve analysis of the materials, interviews with lecturers and students, attendance at lectures, participation in on-line activities and discussions, and analysis of examinations and final course projects.

The initial focus will be on how the key concepts are structured and sequenced, how visual representations are used (and when), and if any rules or mnemonics are used in the course. This will be determined by analyzing interviews with the lecturers to develop an expert view of the above categories and to identify the key concepts of the course. Interviews with learners on key concepts and approaches to learning with a representative sample of students will then be carried out. Through analysis of learning materials, lectures and on-line activities and discussions (and final projects) we will seek evidence that indicates that particular approaches to learning are promoted and evidence that the structure and sequence and use of visual representations either support or hinder student learning.



### **Improving assessment**

In the phase diagrams study, examination results and coursework scores were used to develop a profile of students that indicated a range of abilities. However, student exam results did not correlate with the evidence that students experienced conceptual difficulties. This research will investigate how examinations may be improved in order to serve as better indicators of students' understanding of key concepts within a discipline.

### **9.7 Conclusion**

The thesis has explored and investigated how a phenomenographic approach to collecting and analyzing data about the learners' perspective can inform instructional design. Goodyear (2000) considers how to support real-world learner activities and not the teacher's idealized conceptions of what learner's should be doing.

*... the practice of educational technology needs to be sensitised to the real needs (and activities) of such learners, rather than relying on official accounts of learners' requirements or of what learners should be doing (the tasks they are given).*

(Ibid. Pg. 15)

This thesis has demonstrated that taking account of the experience of the learner improves decision-making in the process of design.



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## **Appendix I**

### **Pre-and Post Interview Questions**



# Pre and Post Interview Questions For Geological Mapping Pilot Study

## Pre-Interview Questions

Subject Number \_\_\_\_\_

- 1 Age
- 2 Sex
- 3 Intent for course, i.e. towards degree, personal interest, work-related, or reason for selecting this course?
- 4 Education, Work experience
- 5 Do you have any prior experience in mapping, either professionally or through hobby?
- 6 What are your expectations of taking the course? What do you hope to learn?
- 7 What do you enjoy most about the course?
- 8 What do you find most difficult?
- 9 What do you think is important or relevant about learning to develop cross-sections in the study of geology?

## Post-Interview Questions

Subject Number \_\_\_\_\_

### Content

- 1 When you first looked at the map, what were you looking for? (particular features or patterns, an overall view)
- 2 What does the geological map show you?
- 3 What approaches to understanding what the map shows you did you take? (general to specific?)
- 4 Can you explain the geological events? Did you build the history starting at the "last" or "first" event?

### Course

- 1 What kinds of difficulties have you had with the course units?
- 2 Do you remember when you first understood how to do cross-sections?
- 3 Have the tutorials been helpful and how?
- 4 Are you part of a study group?
- 5 What do you think might be helpful to understand mapping and cross-sections better?



## Appendix II

### Sample Transcript



### S3 Pilot Study Transcript

Discussion of how he studied engineering drawing exercises where one was given a three-dimensional object, say an air duct, and had to draw a two-dimensional representation. Ss thought that this might be an interesting approach for mapping as well.

I: Here is the cross section. I'd like you to go about it in the normal way you would, and if you need some reminders, here is a sheet of guidelines.

S: So we're going to the section p-q. Well, I would start by transferring the distances along the section of p-q from the map onto the cross-section. This is one of the problems isn't it? (Starts to measure the length of the cross-section line and the length of the topographic profile) Somehow each map that I have ever looked at... it's always marginally different. So it's a cross-section across a river valley with what looks like a dyke in it. Uhm, there are two water courses.

I: Two what?

S: Two water courses, two rivers, two streams that run down. So I have an idea what the cross-section is going to look like now but the problem we have is... okay... so I'll use my little bit of squared paper to

(Starts to transfer the points from the cross-section on the map to the topographic profile, puts the points on the baseline first)

S: The problem I've got here is there is no indication as to the way which... no indications of dip at all are there?

I: No.

S: There's the river... so it looks the beds, ABCDE are in a sequence that is cut by this dyke and then H and I are overlayed in a totally different way, aren't they?

I: When you say a sequence, what do you mean?

S: Well it looks like to me that the beds ABCD, are just laying horizontally one on top of the other, and because there aren't any indications (any dip markers), one can quite safely assume they are horizontal. There's been a movement along this fault F. Then the dyke has come up through after the fault and H&I have been layed on top, so

(Long pause as he continues to plot the points)

S: It seems as if the river, and this little stream here is on a high point, that is what I mean by the, uh

I: This river here is on a high point?



S: It looks as if it coincides with a high point on the profile, which is strange, why should a river be in a high point. I'm sure it's just the slight difference in scale on the profile.....

(Long pause..)

S: That's as far as I would go. Are there any clues to tell you?

I: Well, there is the sheet here with the guidelines, the things that will remind you.

S: Well, there is an unconformity between H and all the others, but in the absence of any indication of strike and dip, um

I: I think basically you are to interpret the strike and dip direction, is there anything that you can see that gives you an indication?

S: Well yes well, there are two problems I have here. Either, uh... it's simply a set of horizontal beds which have been eroded because there is plenty of evidence of water, or this may well be an antiform with the older rocks in the middle, so that it is in that shape with the top taken off. It is difficult to say. If you had a series of layers like an onion

I: So what would it look like underneath the surface?

S: It could either be very flat and the beds appear as you come down the valley, you obviously have erosion, or you could have an antiform which has also been eroded, so let's see, but without knowing the angles of these dips, they could be anywhere between horizontal and vertical

I: Did you say that H and I were horizontal? And you can't tell about the other beds?

S: Well, it certainly could be an antiform with this bed B being at a steeper angle than B here, although the beds are the same thickness, if they were steeper more on one side than the other, more would be exposed at the surface in the shallower dipping angle which is this side, and C is much broader here, than C is there, and you can't see the full extent of D. So if that is the strike line and the rock is in fact dipping on this side of an antiform which is roughly up the centre, it could be drawn here. ...difficult to do accurately without the angles of the dip, apart from the fact that the centre would be in that form, rather than absolutely vertical because of the different outcropping thicknesses

I: Is there anything you can say about the relationship between the river and whether it is antiform or synform?

S: I suppose if it is a synform. no I don't think so, it is possible that the rivers would run down. all that we are saying is that the rocks would be in this sort of form, then chopped off the top. But again, H& I are layed on later

I: So going back to what you said earlier about the sequence, can you do a stratigraphic column or predict the events?



S: Yes, I think the beds.....well, a stratigraphic column. I would think the column would start off with A,B,C,D,E layed conformably one on top of the other in the same environment, then there was a gap, an unconformity, and then H&I are layed on top of that. In terms of what happenned in sequence I would suggest A-E conformably, then the fault F occurred, I can't see any younger rock, and then the intrusion with this dyke XX, and then H& I deposited. And the rivers have obviously changed courses, formed when the ground was upthrust, these are likely to be...I don't know...deposited under water? Then we've got uplift, then erosion to the present topography

I: So as far as you are concerned, because you don't have the strike and dip indicators, you can't be certain about the particular kind of folding going on

S: No, because the rock sequences are in an alphabetical, that may not be relevant, the older rock may be A, but because there is no dip shown then it could go either way

I: Okay

S: In the absence, I can't remember anything else

I: When you did your strat column, you looked at the oldest first, then the youngest?

S: Yes, because of the way the rivers run it seems to me that...I'm not too sure, okay, the way the rivers run this must be physically the lowest point above sea level on the map, and all these others must be higher. So, that although the confluence here is in this area D, it must mean between the cross section and this point, the whole things must come down hill...could be either antiform or synform...more likely that A is the oldest...there is a fold of some description because of the differences in the thickness of the surfaces of the similar beds, certainly C is a lot wider

I: So from the differences in the thicknesses then, there is some kind of fold has happened?

S: So, I still make the point though that if this (the river) is the lowest point above sea level, most of the erosion has occurred from the North to the south, so it may well be that there has been more erosion and therefore there is a difference in the degree of slope if you like...that being quite steep. Looking at the profile here, the slope on each side looks very similar, which would indicate that there is a difference in the bedding, but again, which way it folds is a question

I: Okay, if you are happy with that then



## **Appendix III**

### **Geological Mapping Learning Materials**



# **Learning About Folds**

**Janet McCracken**

**Institute of Educational Technology**



Thank you for participating in this study. I hope the learning materials will be helpful to you. Please work through the materials at your own pace. It should take you about 45 minutes to complete. Don't worry if you don't finish, just go as far as you can.

Please be assured that all materials are confidential, and no results will be reported for individuals. When I analyse and report the data, I will be using data from the entire group. Individual scores will not be available to course tutors or managers. They are solely for use in this research study.

Note: Except where indicated, all diagrams are taken from s236 materials or were developed specifically for this lesson by Bonita Thomson or Janet McCracken.

**OU STUDENT IDENTIFIER:**

**AGE:**

**DATE:**



## 1.0 Objectives

The following objectives apply to this lesson:

1.2. Given a simple geological map, you will be able to identify and explain how V patterns on streams indicate dip direction, and provide clues for interpreting underlying geological structures.

1.3. Given a simple geological map, you will be able to identify the visual features which indicate the presence of fold structures.

1.4. Given a visual representation, you will be able to discriminate between antiforms and synforms.

## 2.0 Overview

A geological map represents a plan view of the earth's surface in terms of its underlying geological structures. A geological cross-section is an interpretation of the sub-surface geology deduced from the distribution of rock types mapped at the surface. It is a vertical slice view of the sub-surface at a particular line across a geological map. The 'top' of the cross section is the topographic profile and shows the irregularities in the land surface and it shows how the geological structure can relate to hills and valleys.

You will recall that there are many types of geological features which can be deduced from a plan view, including folds, faults, and igneous intrusions, which can assist you in interpreting the underlying geological structures. This lesson deals with interpreting folds on the kind of simple geological maps you have been working with in this course, to help you to better visualize and understand cross-sections.

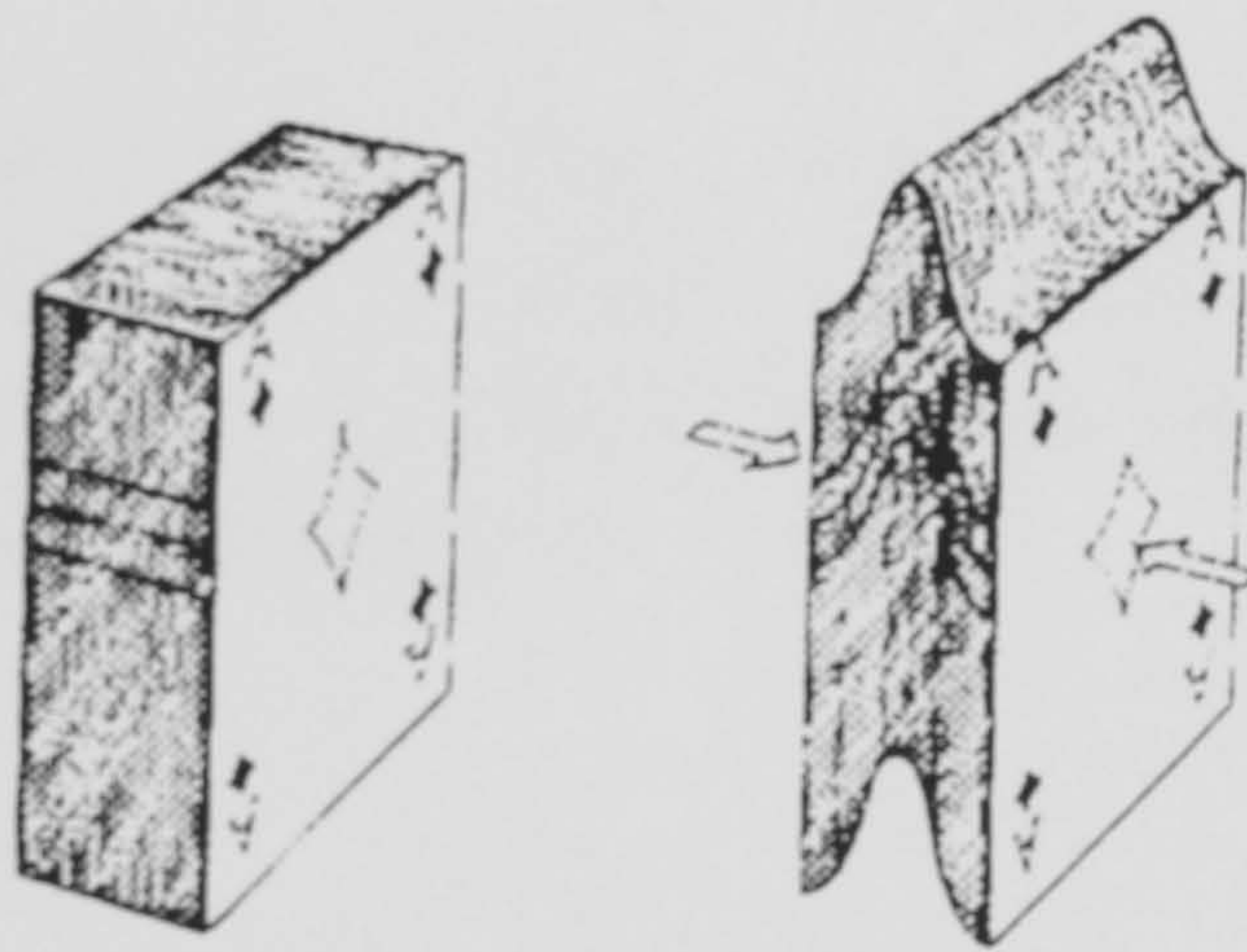


### 3.0 Learning Exercises

The remainder of this lesson presents a series of learning exercises, starting with a brief introduction to a topic, followed by examples, then followed by instructions for answering questions, or working with diagrams. Once you have completed the instructions, a feedback sheet on the exercise shows a correct solution.

#### Introduction

Folded geological structures refer to the direction in which beds of rocks are sloping. Beds are folded as a result of compression by lateral pressure over time. Folds occur when rocks are sufficiently flexible to deform and depend both on the particular rock type and the nature of the deformation.



Over time, a topography develops which can reflect the underlying geological structures. As folds develop, they are subjected to weathering and erosion, and the extent to which they are affected depends on the relative resistance of the rock types; harder rocks, such as well-cemented sandstone, are more resistant to erosion than softer rocks, such as mudstones. The changes to the rocks due to erosion and weathering affect only the surface features of geological structures, i.e. the topography, but the original structure remains the same at depth. This is an important idea to remember as you are learning about folds.



### 3.1 Comparing Synforms and Antiforms

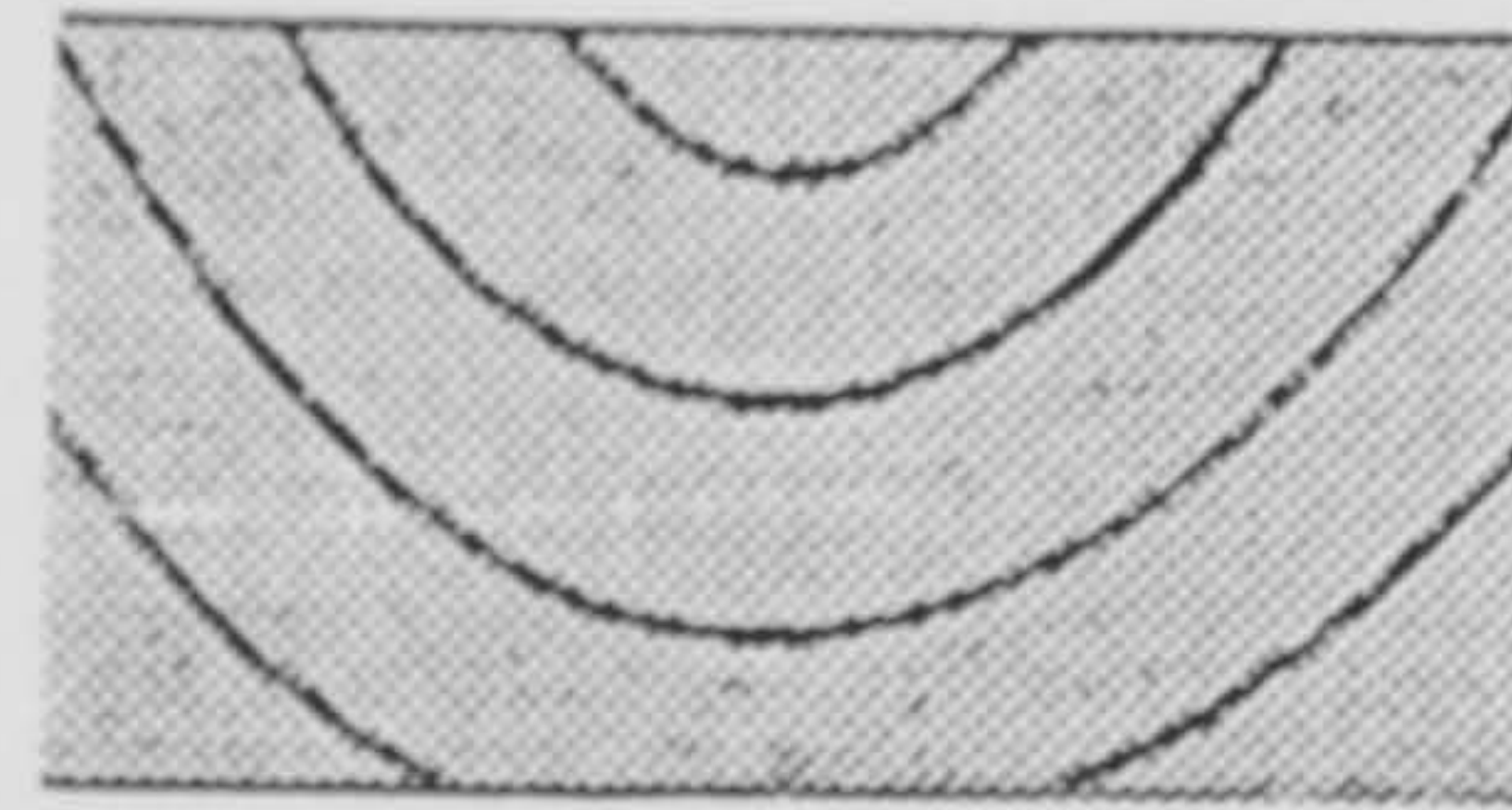
#### Introduction

You will recall that there are two major types of fold structures; antiforms and synforms. A synform is formed when rock beds are folded down in a trough. An antiform is formed when beds are folded in an arch.

Antiform



Synform



It is sometimes useful, when trying to learn about folding, to consider how horizontal bedding appears in comparison to antiforms and synforms so that you can see how the various structures differ from one another visually and structurally.

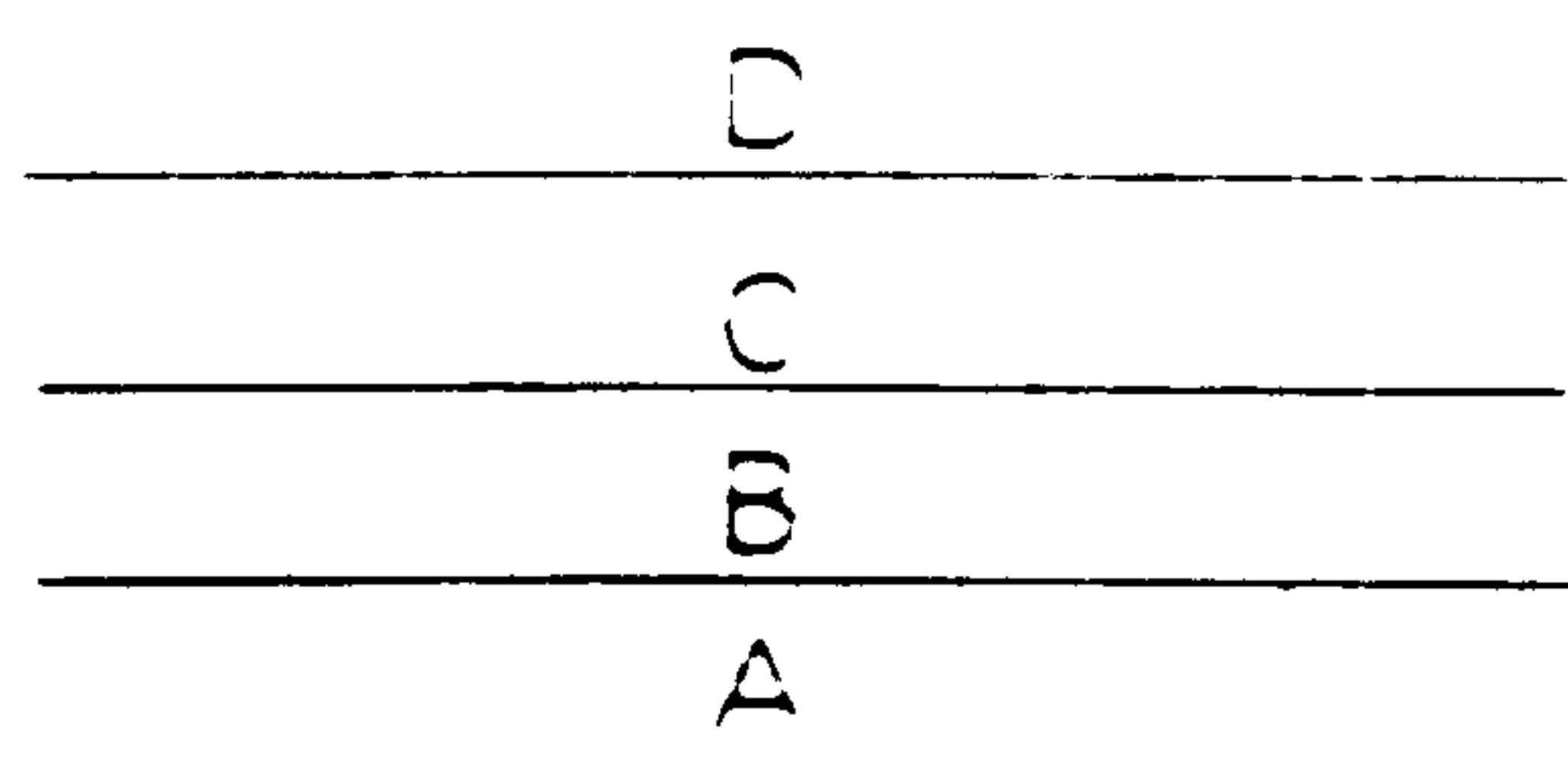


### 3.1 Learning Exercise : Comparing Antiforms and Synforms

#### *Instructions*

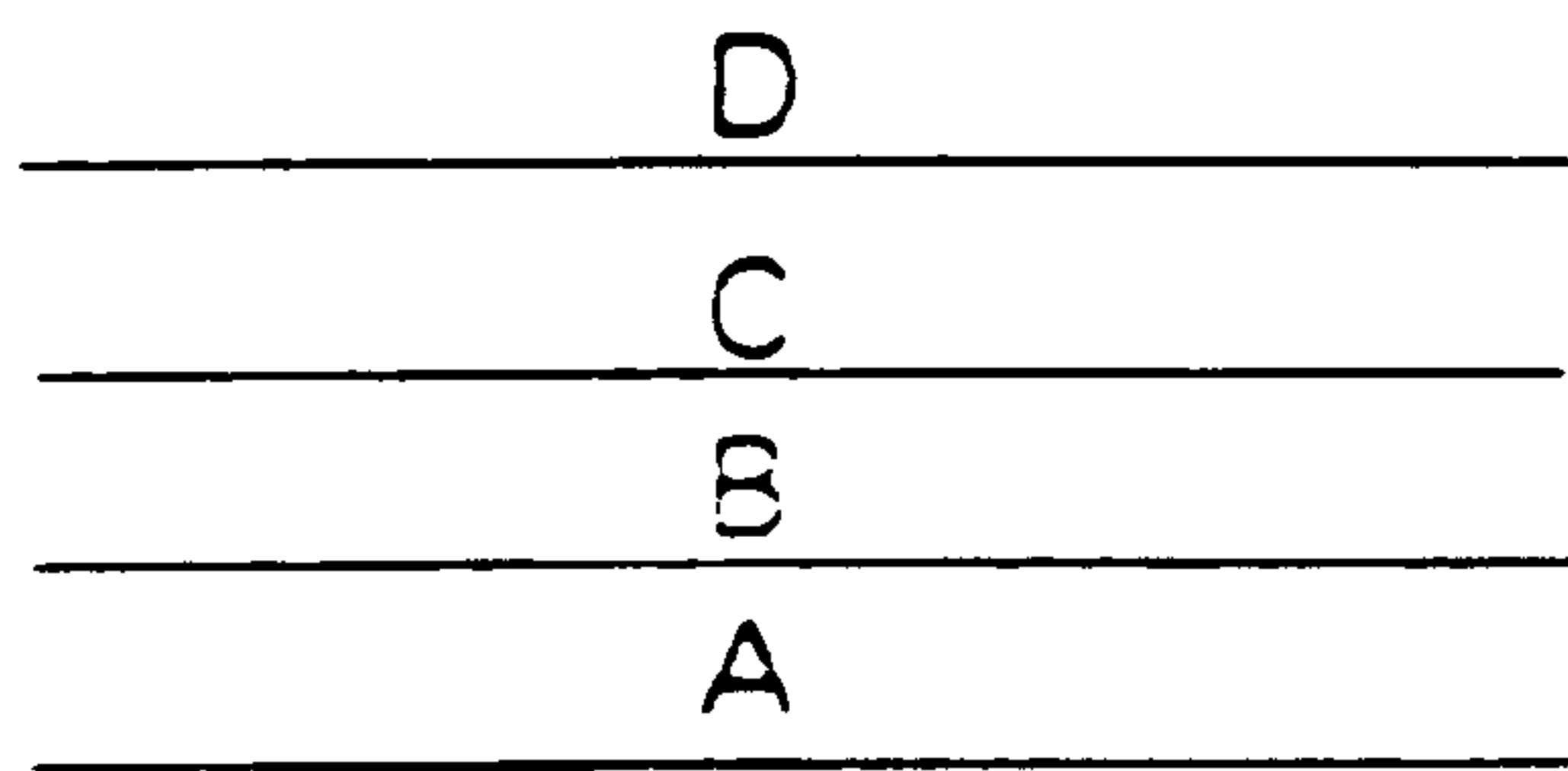
Using the horizontal beds illustrated, sketch how these beds would look if folded into a synform. Then sketch how the beds would look if folded into an antiform. Label the beds.

Horizontal Bedding



Synform

Horizontal Bedding



Antiform



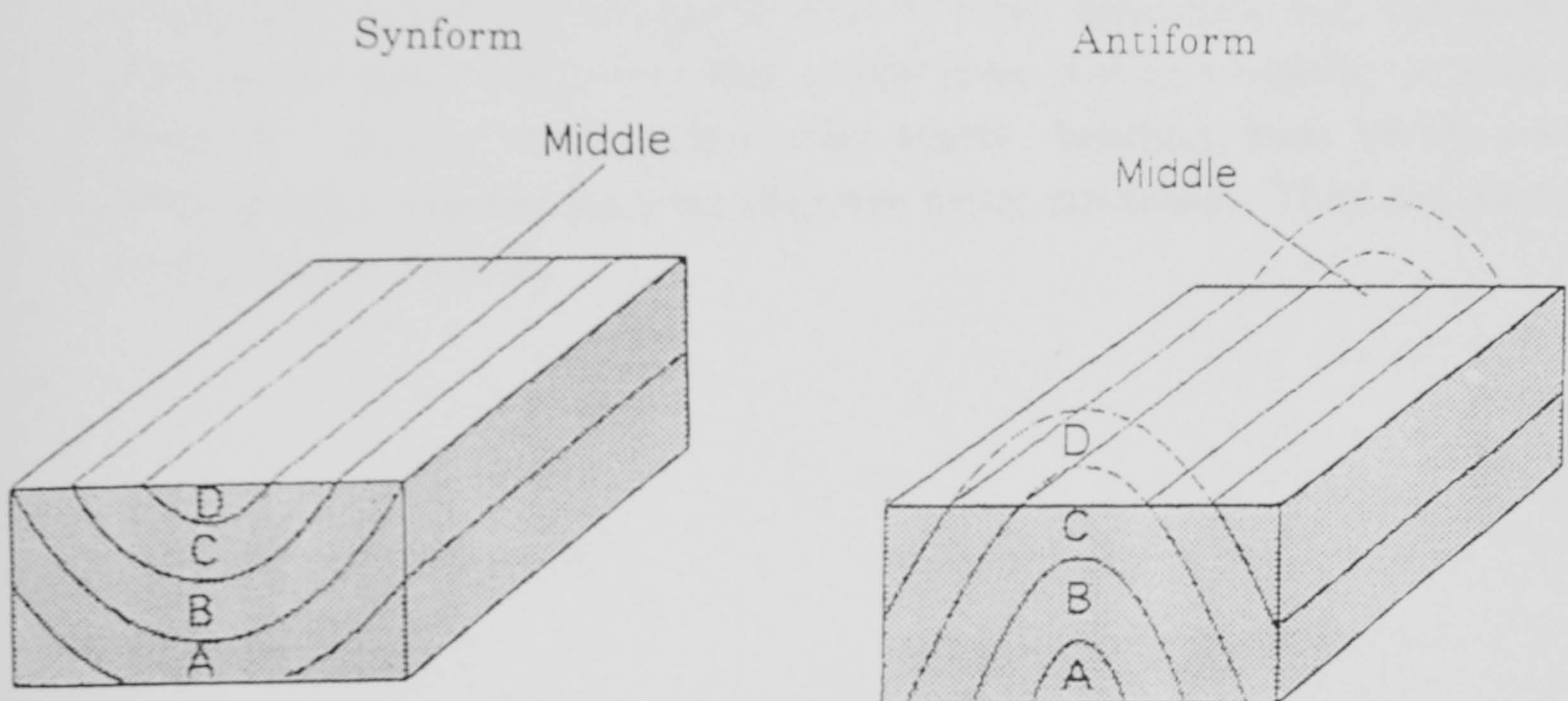
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### Exercise 3.1 Feedback

You can see from the following diagram that D bed of a synform is located in the middle of the formation. Also, you can see how C bed is in the middle of the antiform. Consider that if erosion continued, either B, or A bed might be at the middle of the antiform. You can also see how the fold appears on top of the block diagram.

Notice for the antiform, there are dotted lines drawn in which show how the antiform would have looked previous to erosion and weathering.



#### *Instructions*

Transfer the labels on the beds in the cross-section to the top of the block diagram to give yourself an idea of what the formations would look like on a geological map.

### 3.1 Summary

You have constructed an antiform and synform, simulating the effects of lateral pressure on horizontal bedding and have seen how these structures appear in plan view. From the above block diagrams, if you were to look on at the top of the block, you notice that from a purely visual point of view, there is no obvious distinction between the appearance of the synform and antiform on the surface. In the following exercises, we will consider the kinds of topographic clues which help in this distinction.



## 3.2 Understanding Continuous Processes

### Introduction

When looking at geological maps, it is important to remember that the present day is very very recent, like it happened this morning, as compared to geological time and what you have left underneath is the geological structure which has been there much much longer. And so you have present-day erosion processes cutting down into this geological structure. It is helpful to think about the formation of an antiform; folds begin by slow buckling of the crust by sideways pressure. Any water which falls on slightly upwarped crust will run down that hill, and start eroding the rocks, not necessarily as one river, but as a number of small streams. So the moment the crust starts bending, beds which are arching are weakened because they are being stretched. They are more susceptible to erosion.

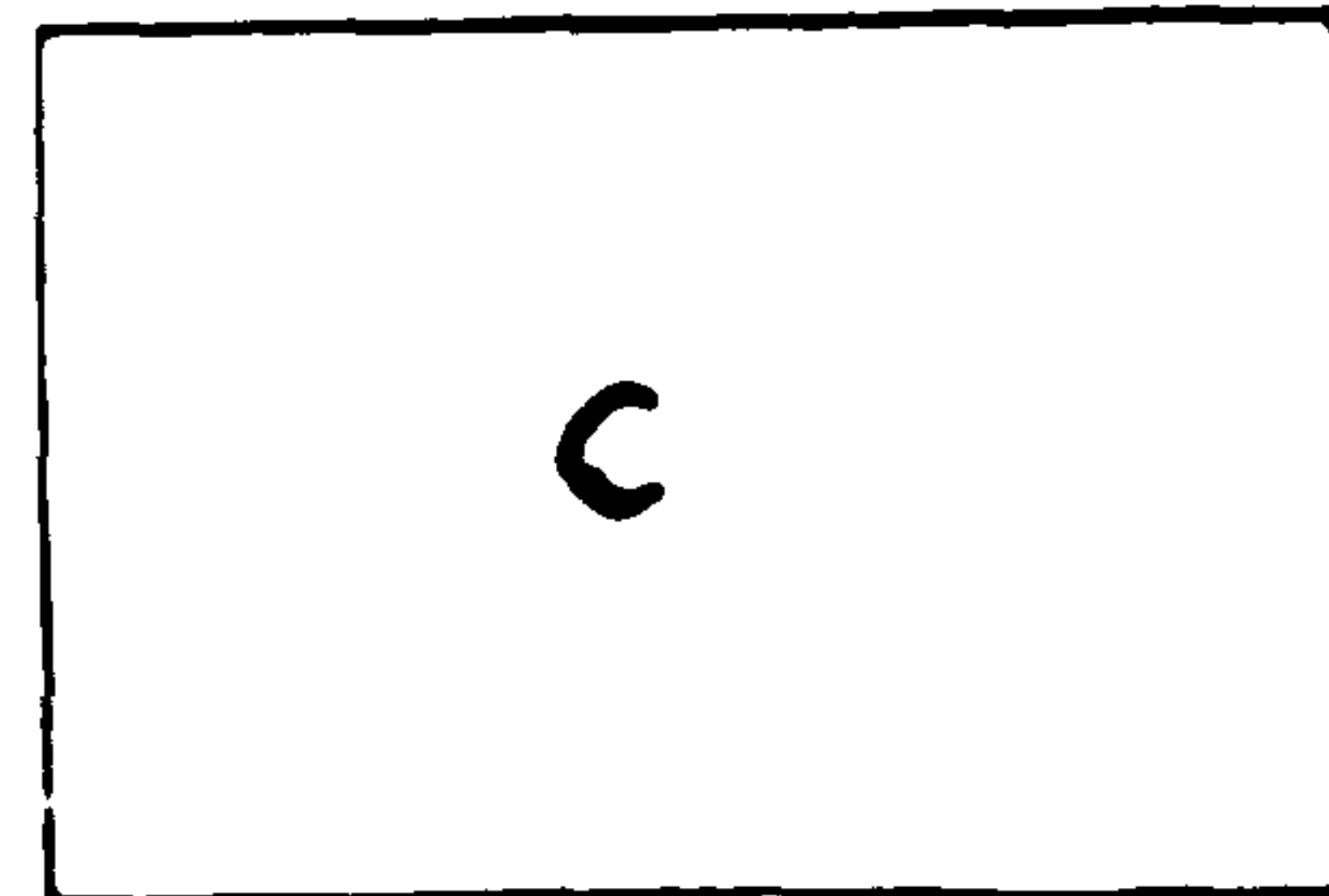
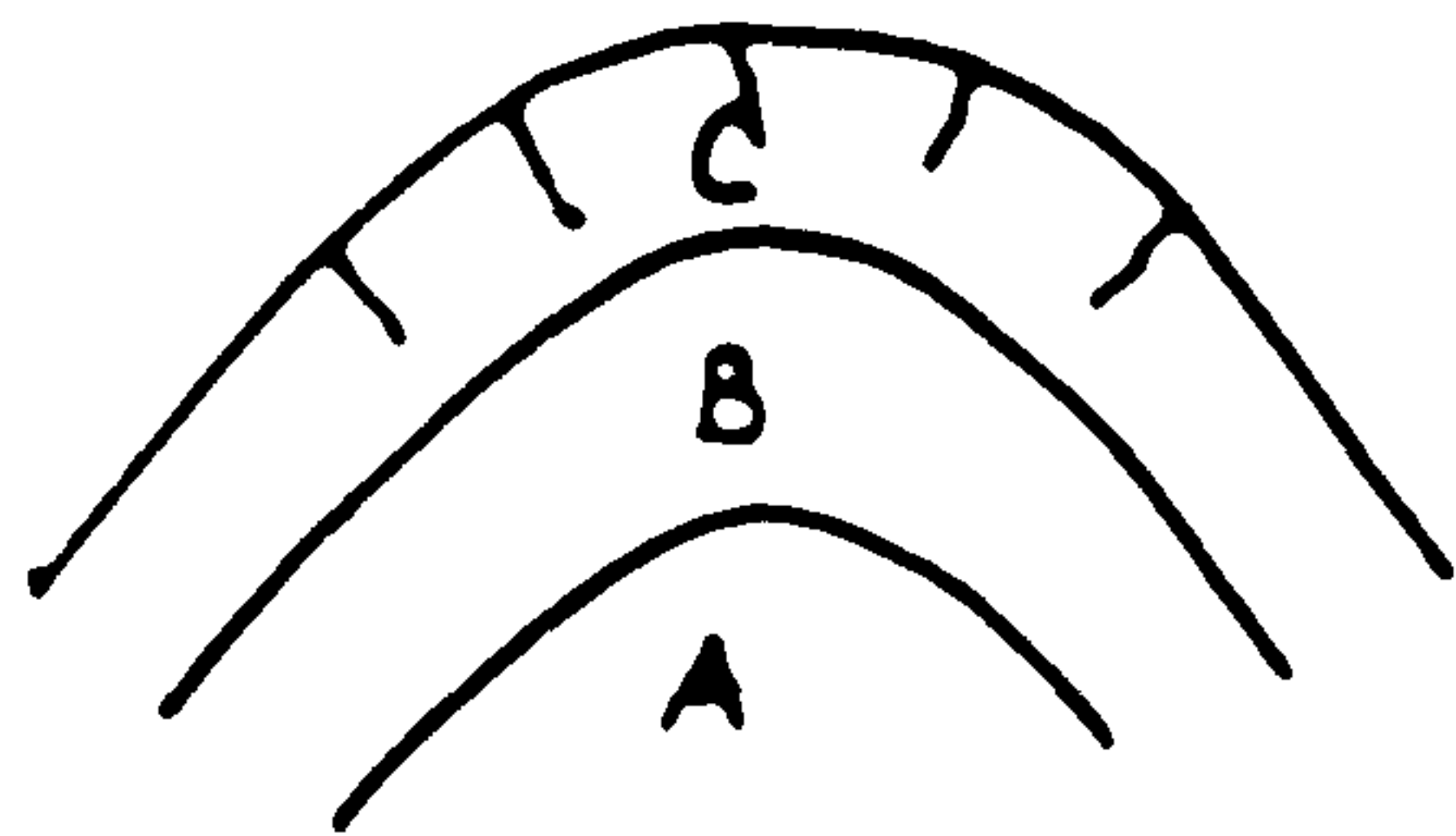


### 3.2 Learning Exercise 2: Understanding Continuous Processes

The following series of diagrams show the effects of erosion over time on an antiform. Look carefully at each of the stages and how each stage would be look on its corresponding geological map.

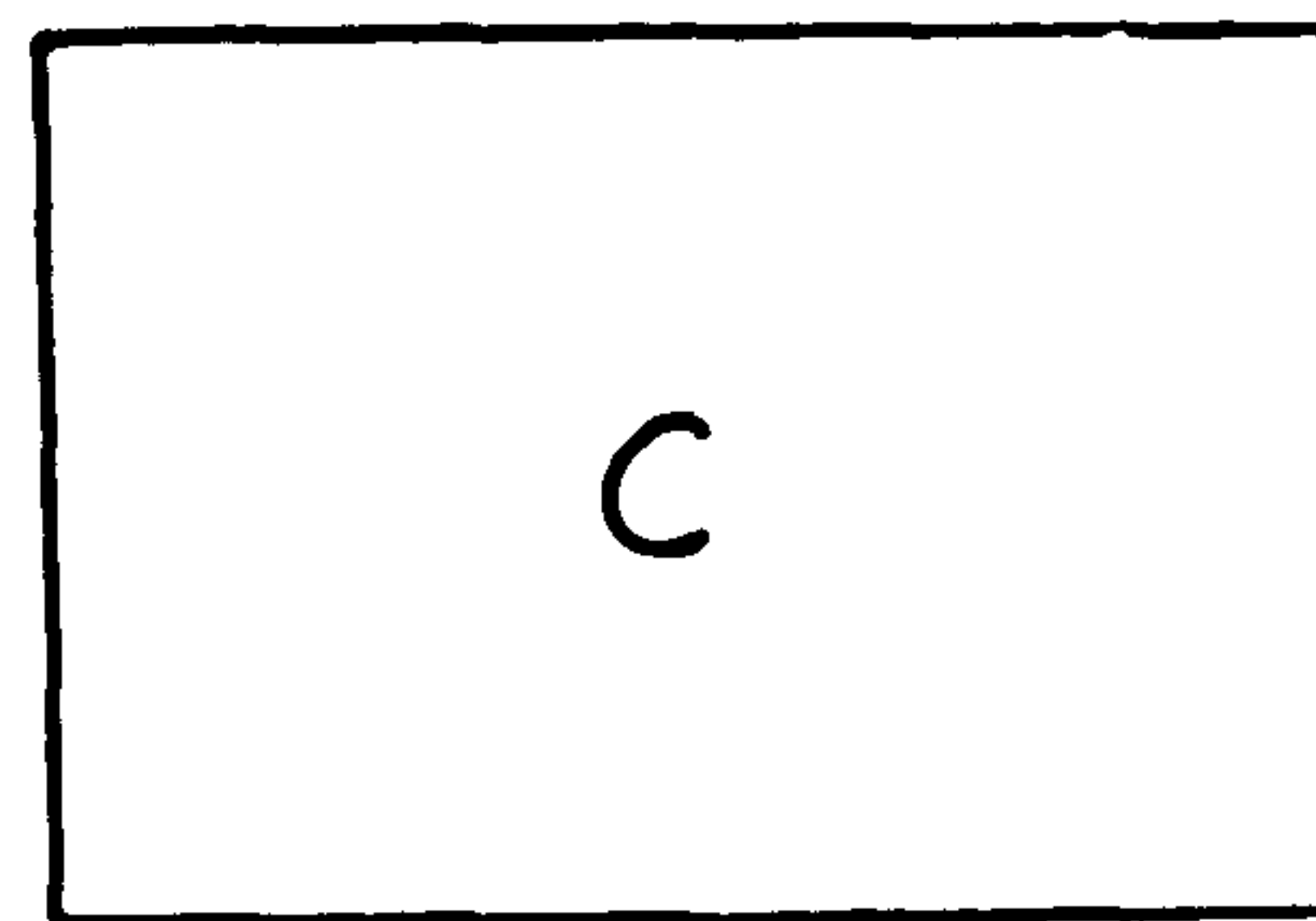
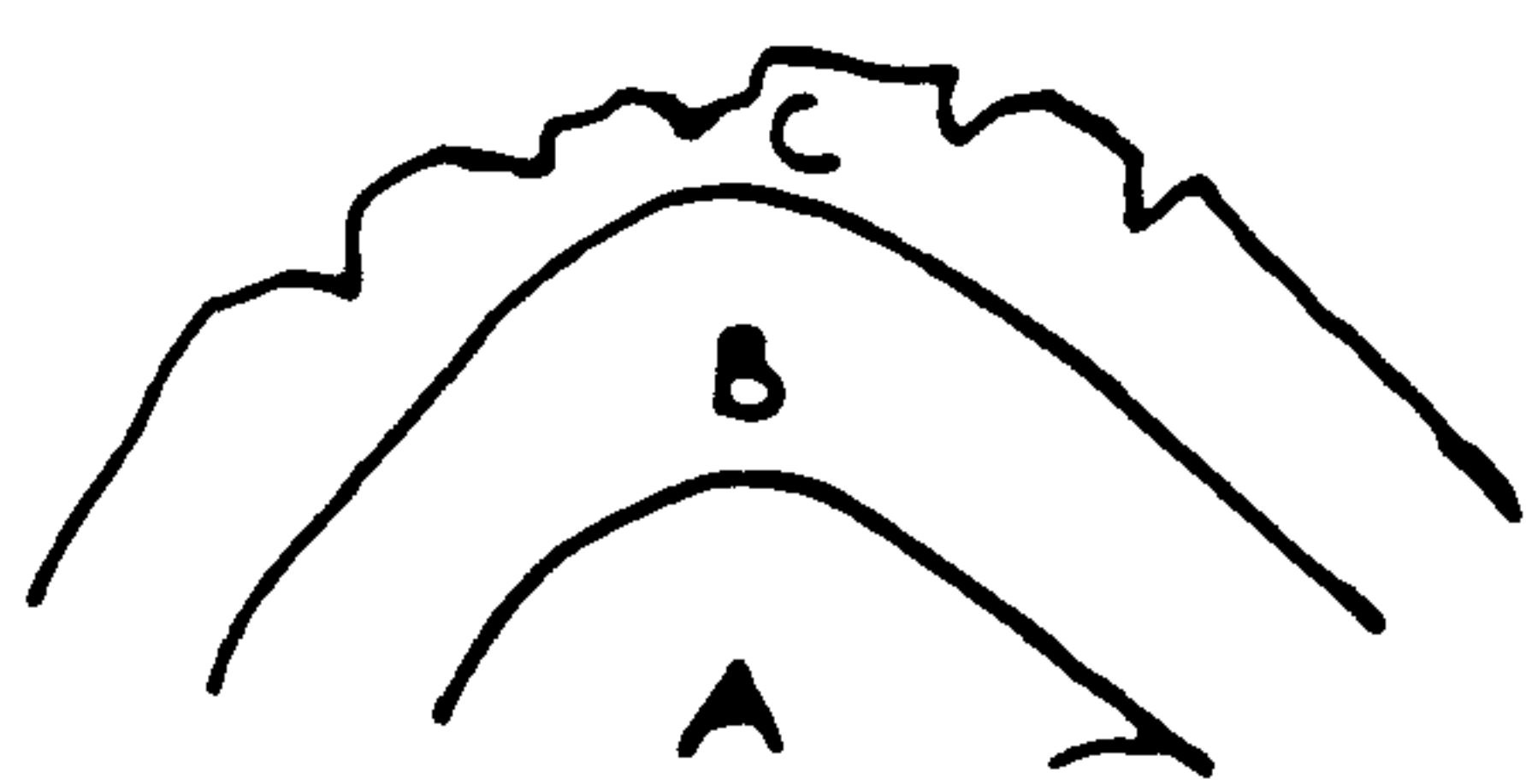
*Cross-Section View*

*Map View*



Stage 1: Beds are folded

Stage 1: Only Bed C would be exposed



Stage 2: Erosion and Weathering

Stage 2: Only Bed C would be exposed

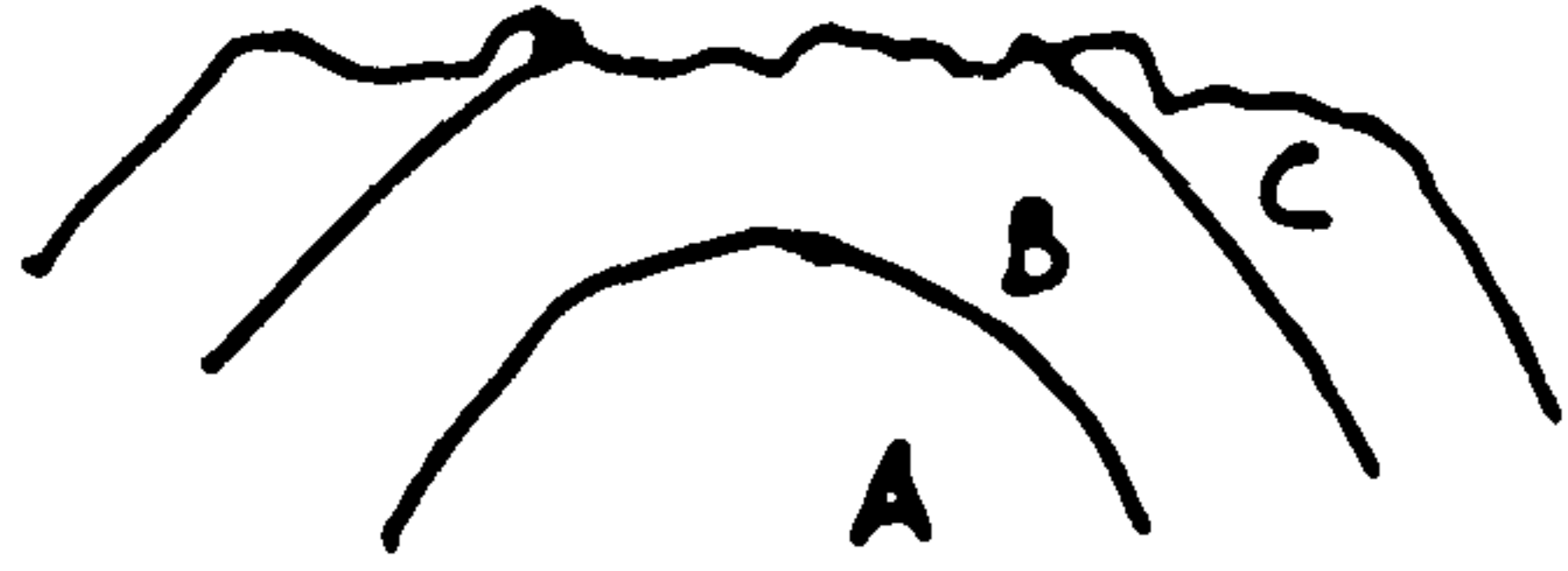


**Instructions**

Fill in the letters of the formations you think would appear on the map for stages 3 and 4.

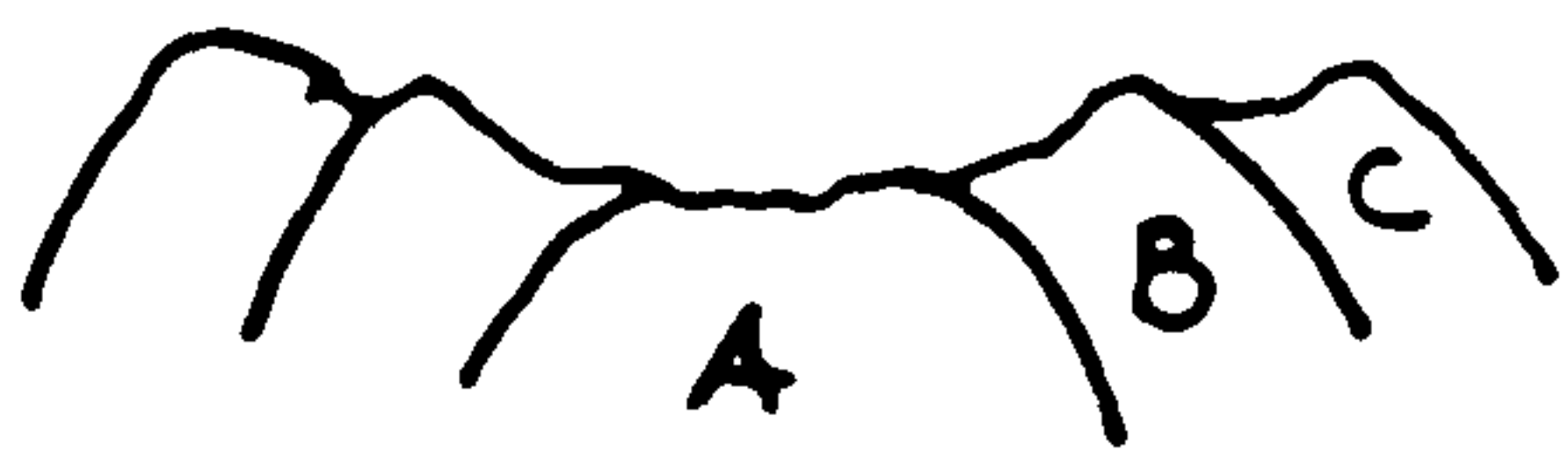
*Cross-Section View*

*Map View*



Stage 3. Erosion and Weathering Continues

Stage 3: Map View now shows which beds? \_\_\_\_\_



Stage 4: Erosion and Weathering Continues

Stage 4: Map View now shows which beds? \_\_\_\_\_



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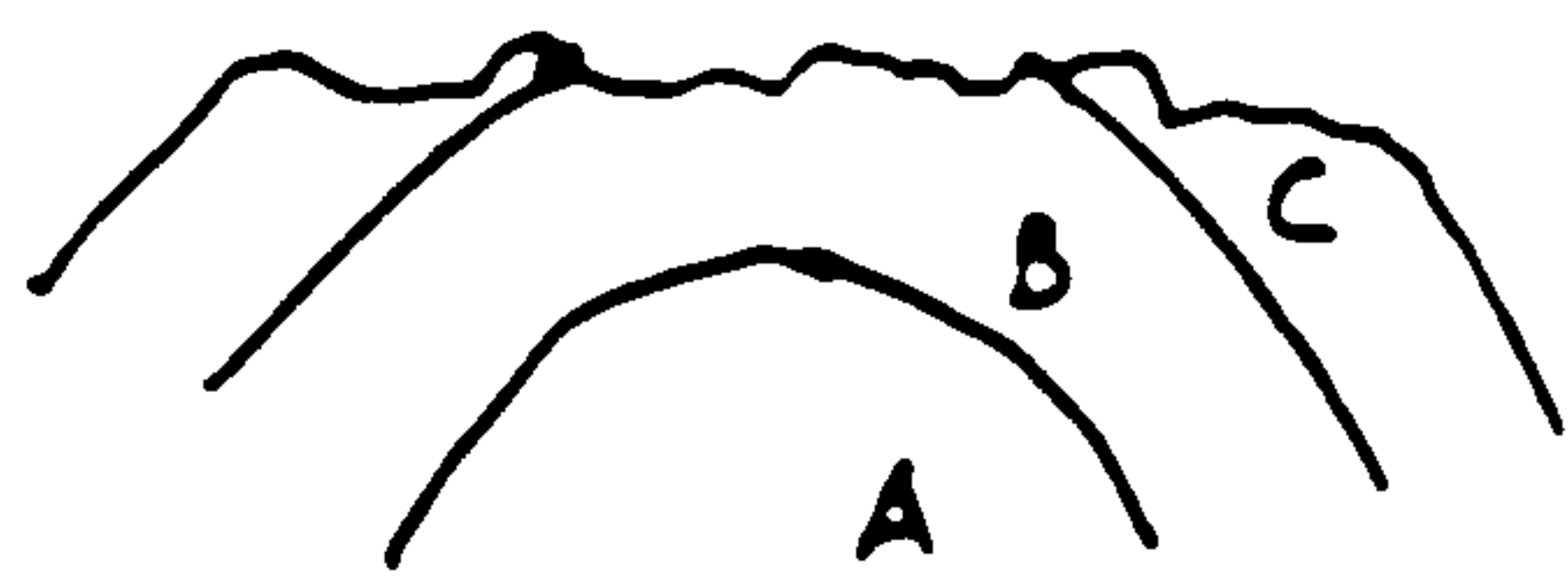


## 3.2 Feedback

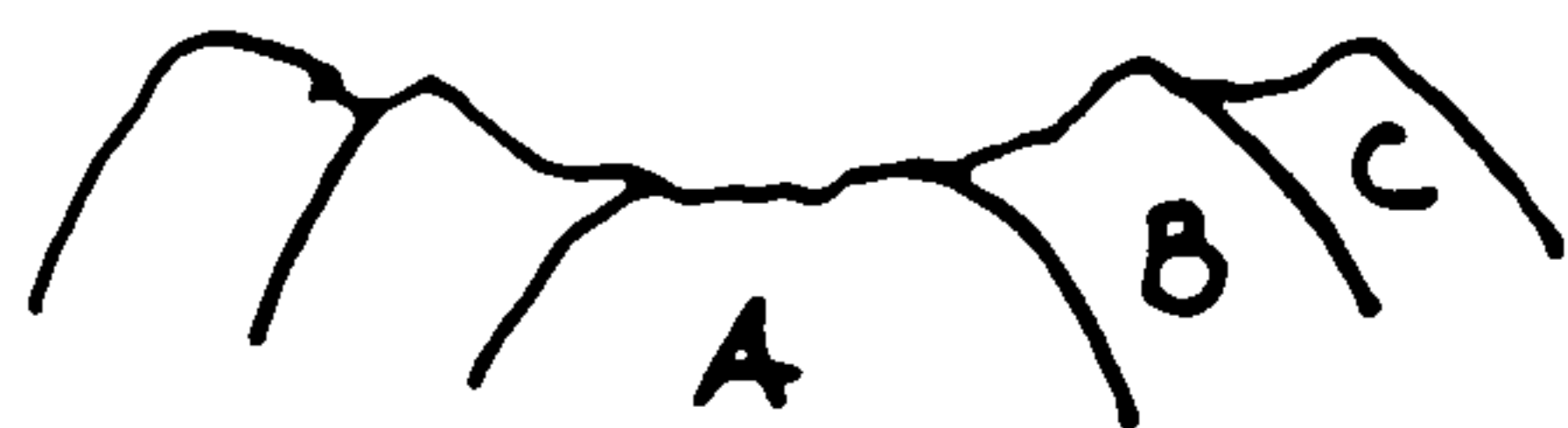
The diagram illustrated the surface processes which may happen as an antiform develops. In Stage 1, the horizontal strata begins to buckle because of lateral pressure into a series of developing antiforms and synforms. We are looking only at an antiform in the current example.

As the antiform develops, the beds weaken across the crest, making them prone to erosion. Bed C is gradually eroded, exposing Bed D, which in turn is eroded away exposing Bed A, in the middle of the antiform. If the outer beds are more resistant, they will form steep slopes which face each other across the middle of the antiform, leaving a topographical low area in the middle.

*Cross-Section View*

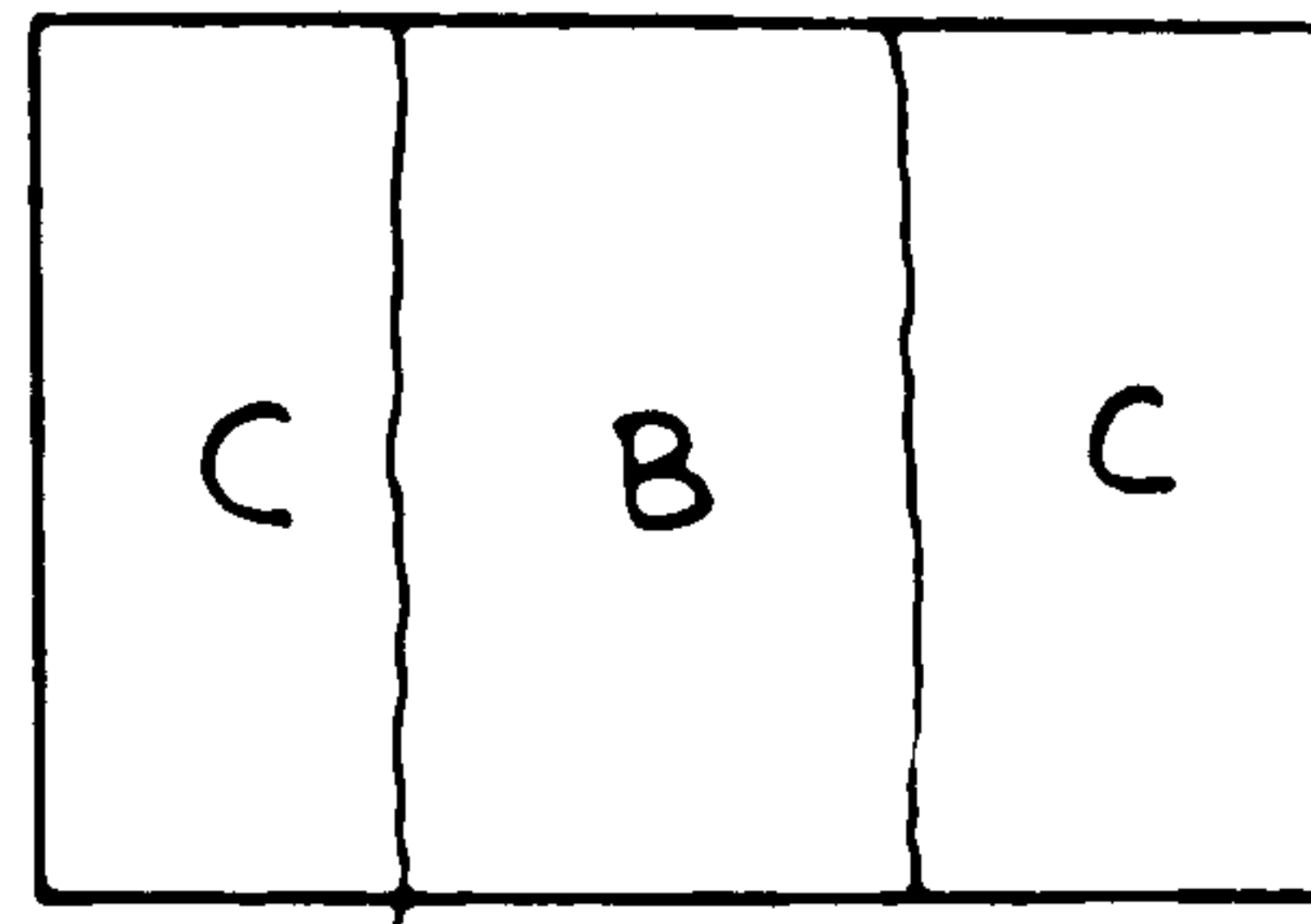


Stage 3: Erosion and Weathering Continues

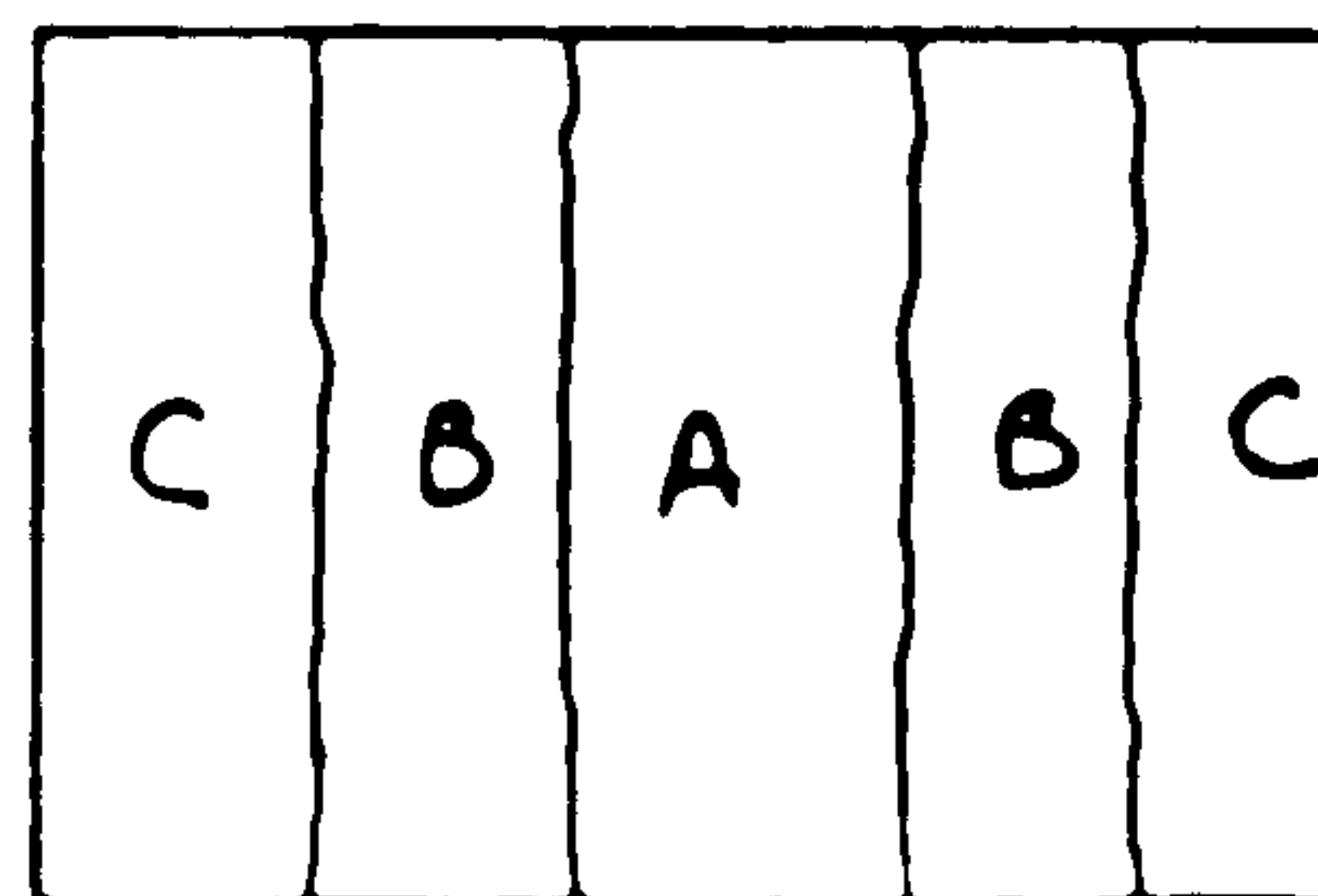


Stage 4: Erosion and Weathering Continues

*Map View*



Stage 3: Map View now shows Bed C and B



Stage 4: Map View now shows Bed A, B and C

### Summary

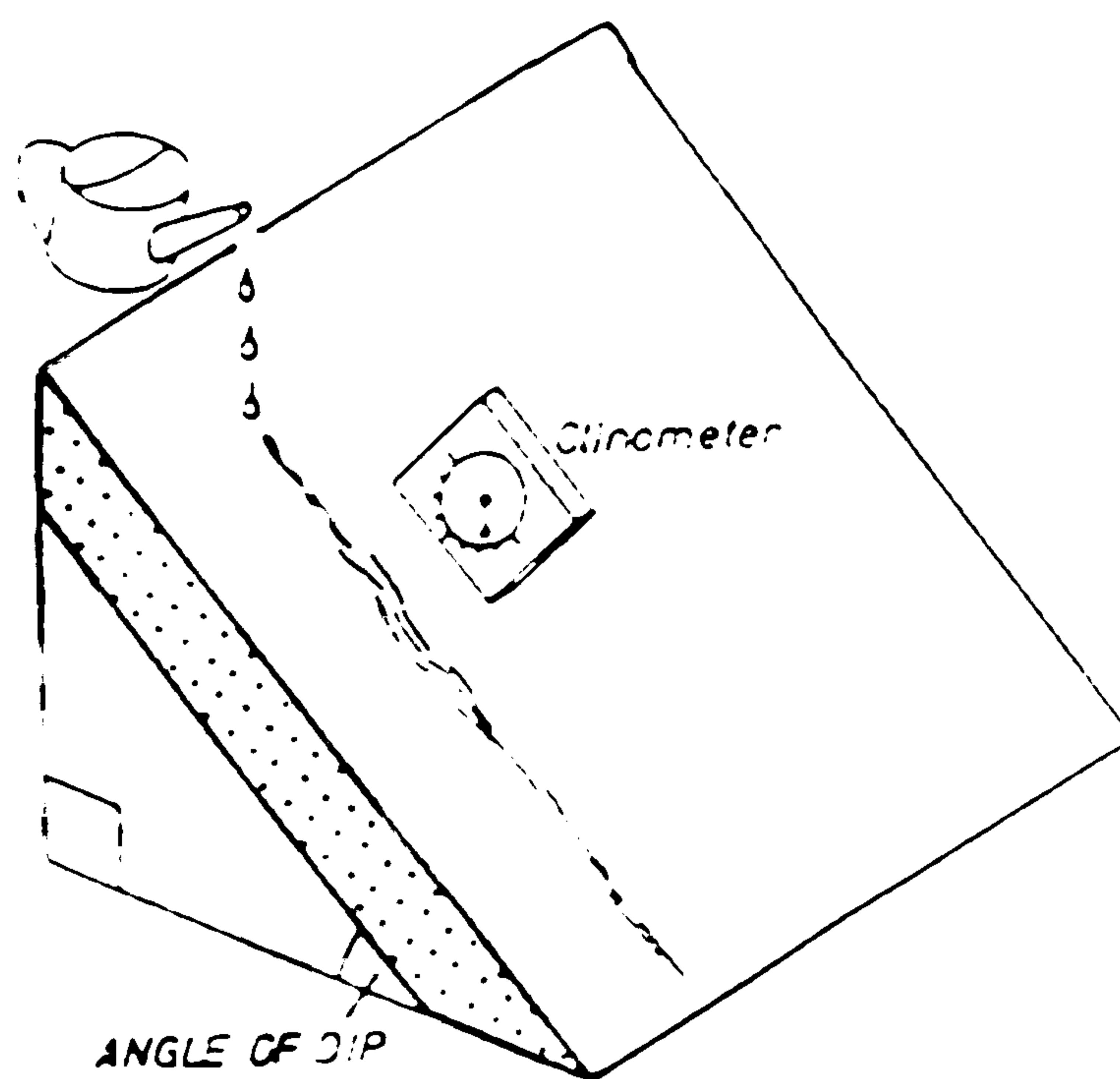
You have seen the effects of erosion on an antiform over time, and how the map view of the formation changes as beds become exposed at the surface. We will now look at the concepts of dip and strike.



### 3.3 Determining Dip Directions

#### Introduction

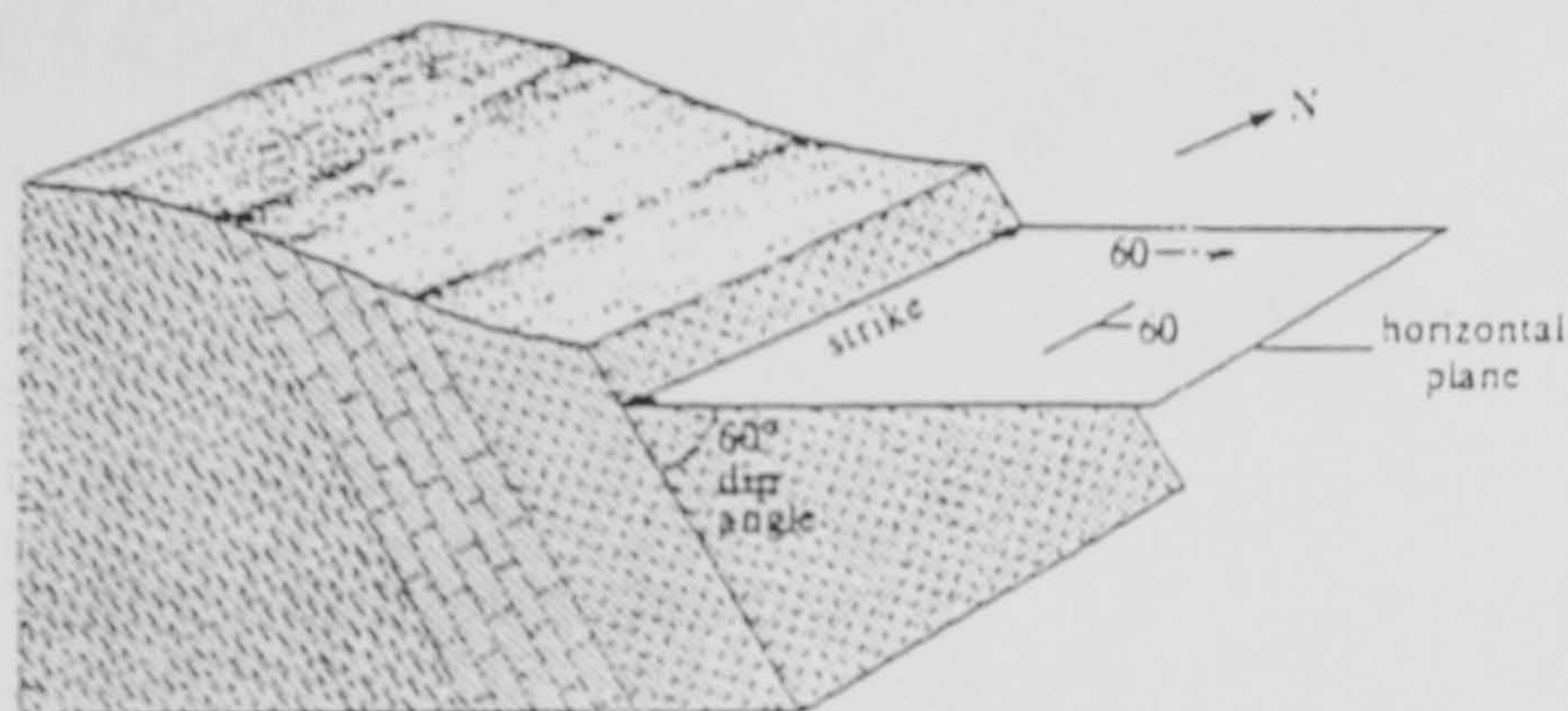
An essential part of reading a geological map is the ability to determine whether a fold is an antiform or a synform, which involves the concept of dip. Dip is the slope of a geological surface. The direction of dip can be visualized as the direction which water would flow if poured onto a tilted plane. The dip of a geological surface can be anything from 0 degrees to 90 degrees. Zero dip means the surface is horizontal, 90 degrees dip would result in a vertical surface. Any dip, then which is greater than zero results in a sloping surface and the direction of the dip is the direction in which the surface slopes.



(from Lisle, 1991)



In order to understand how to indicate the direction of dip, you must also recall the concept of strike. Look at the following diagram which illustrates the concept of dip and strike.



Strike is the direction of a horizontal line on an inclined surface, such as a bedding plane, and is always at right angles to the dip direction. In the above diagram, notice that the strike line is a horizontal plane, and that the angle of the dipping bedding plane is 60 degrees towards the east. You can imagine the horizontal plane in the diagram as a flat board, the edge of which you are holding against a rock surface.

As you will remember, the symbols which represent the orientation of strata are:

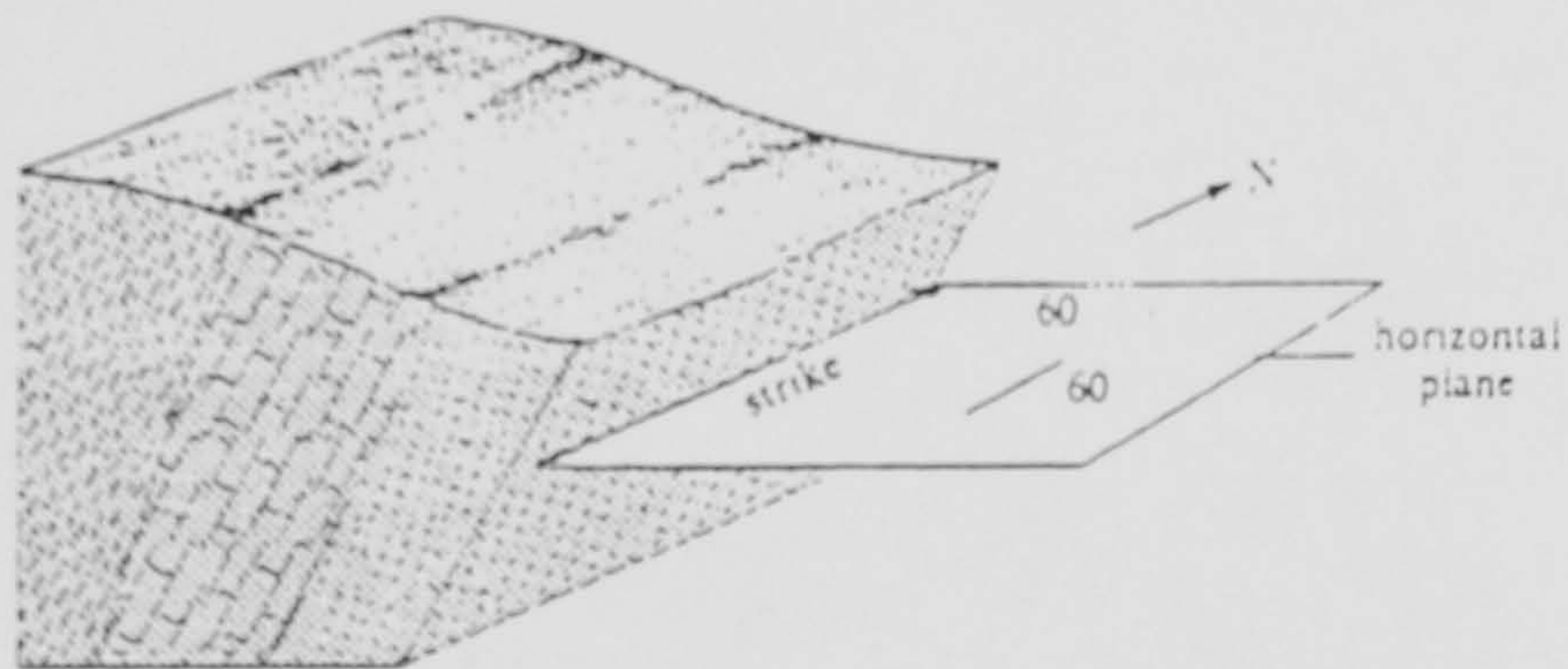
- + horizontal strata (zero dip)
- └ beds are dipping above zero degrees.
- ┆ beds are vertical



### 3.3 Learning Exercise 3: Determining Dip Direction

#### *Instructions*

How would the above diagram look if you were to have a dipping bedding plane dipping 60 degrees *west*? On the following diagram, change the strike and dip direction as you think it should appear.



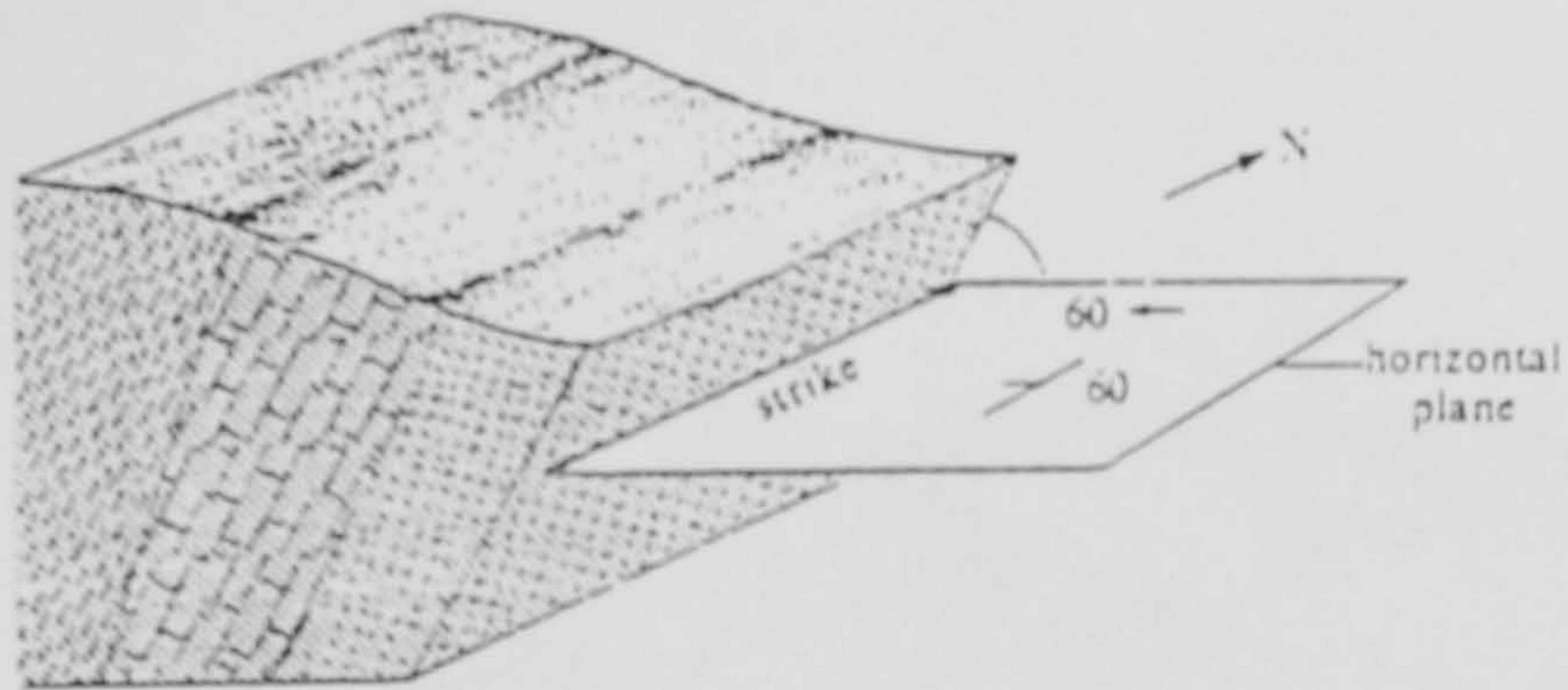


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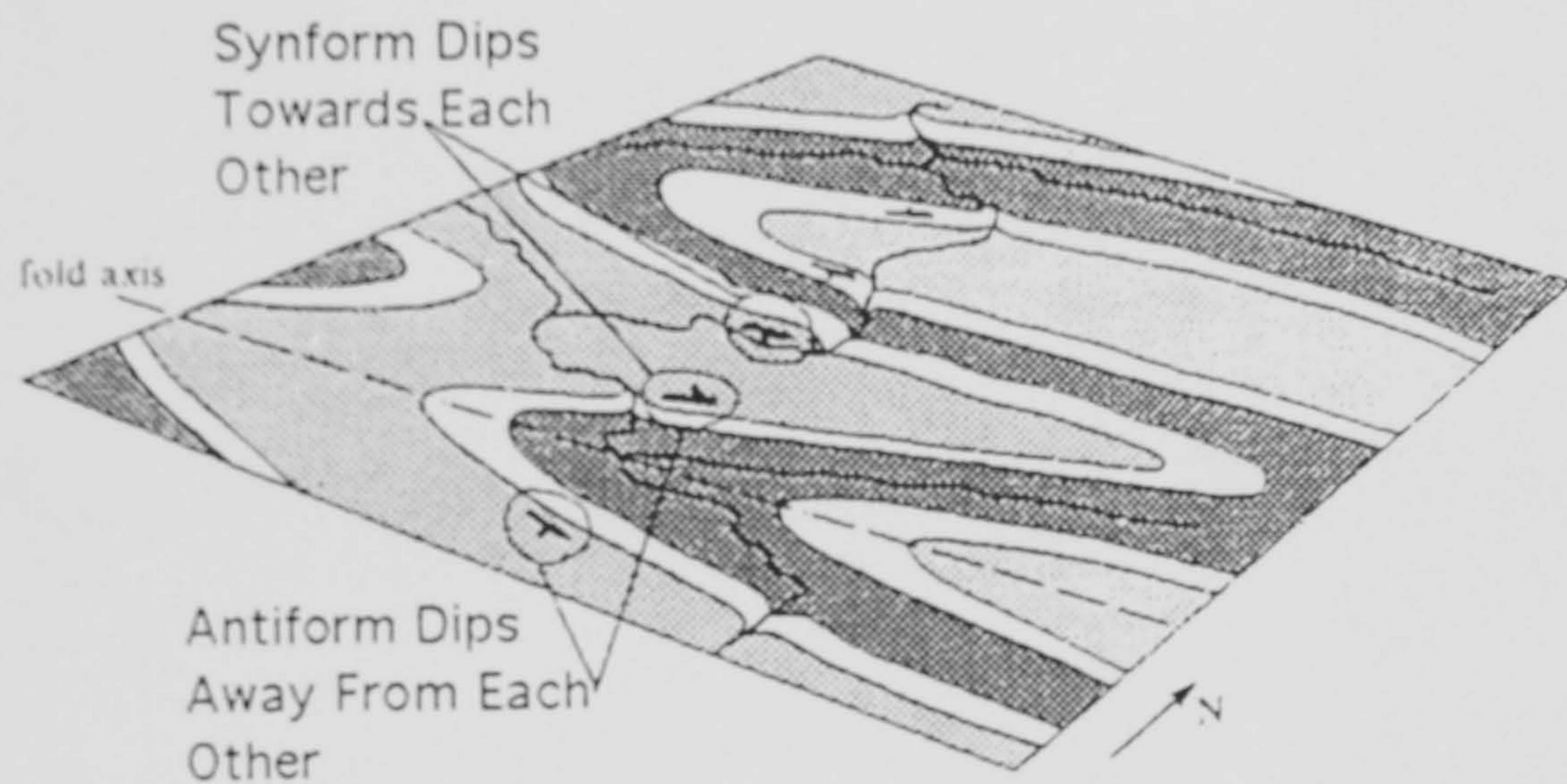
### 3.3 Feedback

The following diagram shows the correct dip and strike directions. The bedding planes are dipping at a 60 degree angle relative to the strike plane to the west.





The following diagram shows how dip and strike are represented in map view. You will notice that the fold structures do not appear as horizontal lines across the map. That is because these folds are *plunging*, the original folded layers have been worn down by irregular erosion, producing wavy, instead of horizontal, outcrop patterns on a map.



This diagram shows two antiforms and one synform. The dip for an antiform indicates that the bedding is dipping outwards on either side of the middle of the fold, and forms an arch. The dip for a synform indicates that the bedding on either side of the middle of the fold is dipping inwards, that is, down in a trough. It may be helpful to think about a synform as the shape of a sink. Remember that we are referring to the geological structure, not the topography.





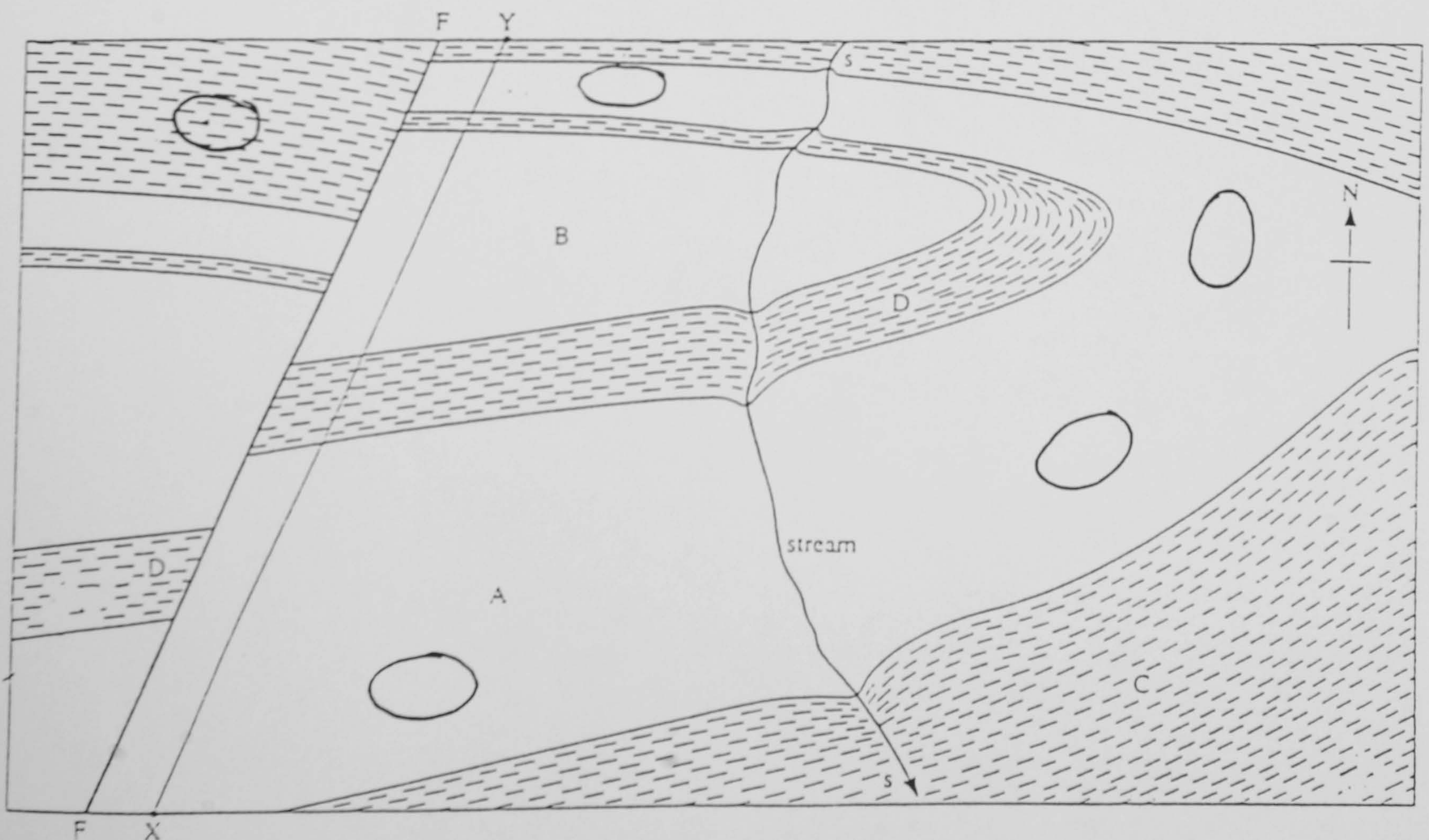
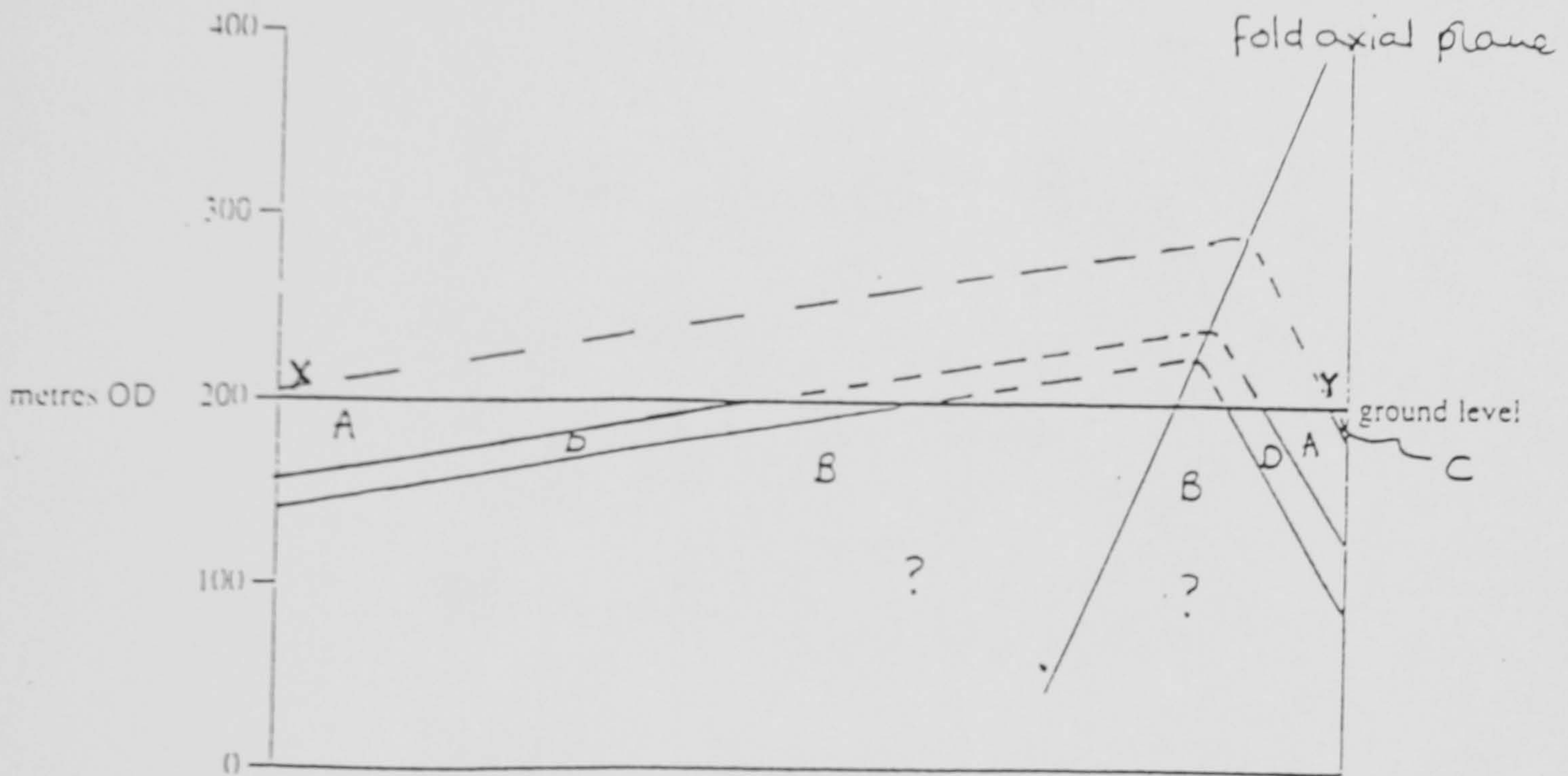
### 3.4. Learning Exercise 4 : Dip Directions From Cross-Sections

#### Instructions

The purpose of this exercise is for you to practice identifying dip direction. Study the cross-section which identifies whether a fold is a synform or antiform. On the map provided, you are to

1. Mark the correct dip directions in the circles provided.
2. Mark any axial planes, using the symbol:

(synform , antiform )



100 m

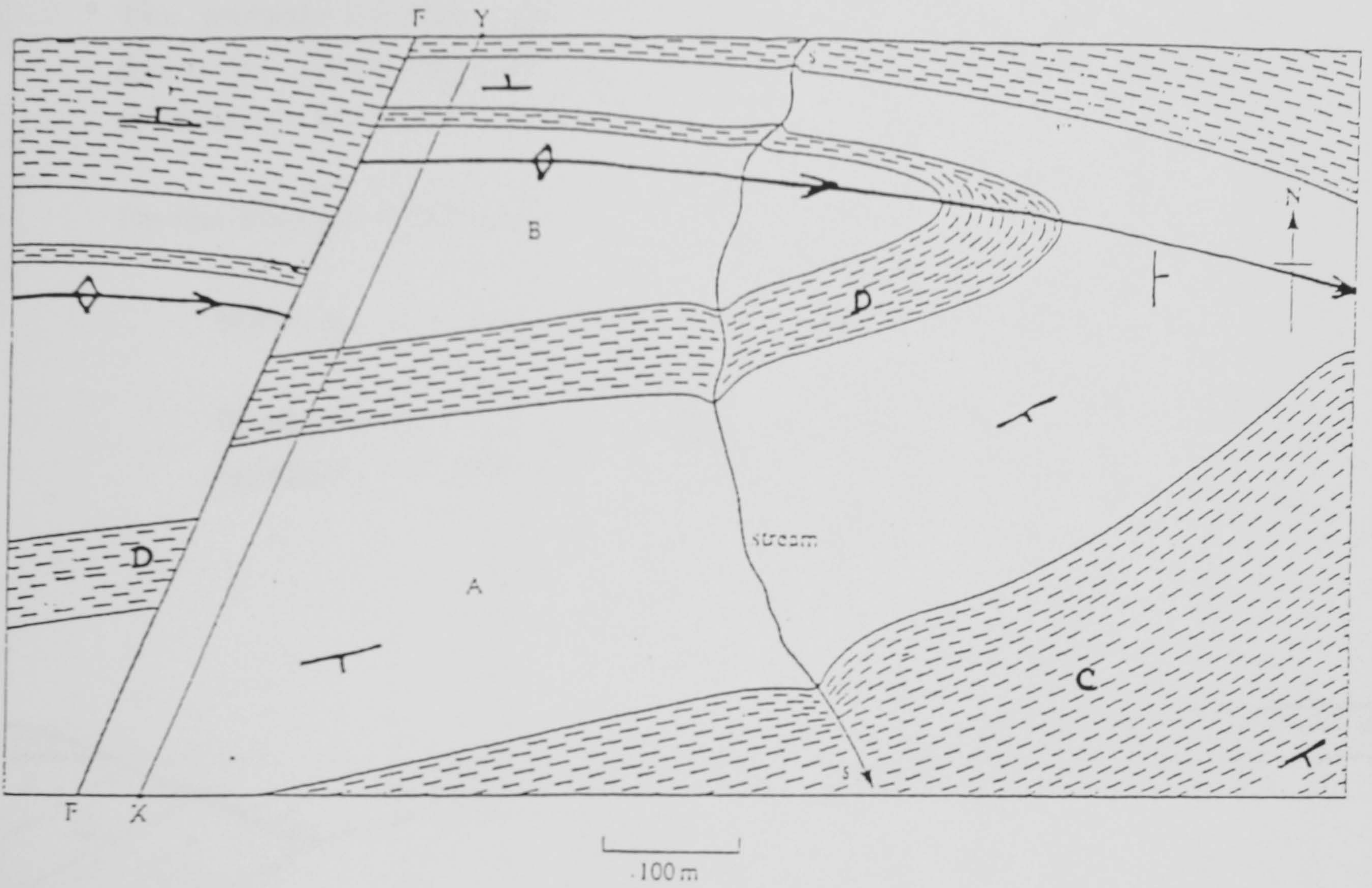


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until you have tried  
to complete the exercise.



### 3.4 Feedback

3.4 Here is the map view solution with the dip directions and the axial plane marked in.





### 3.4 Learning Exercise 4 Continued : Determining Dip Directions from Cross-Sections

#### Instructions

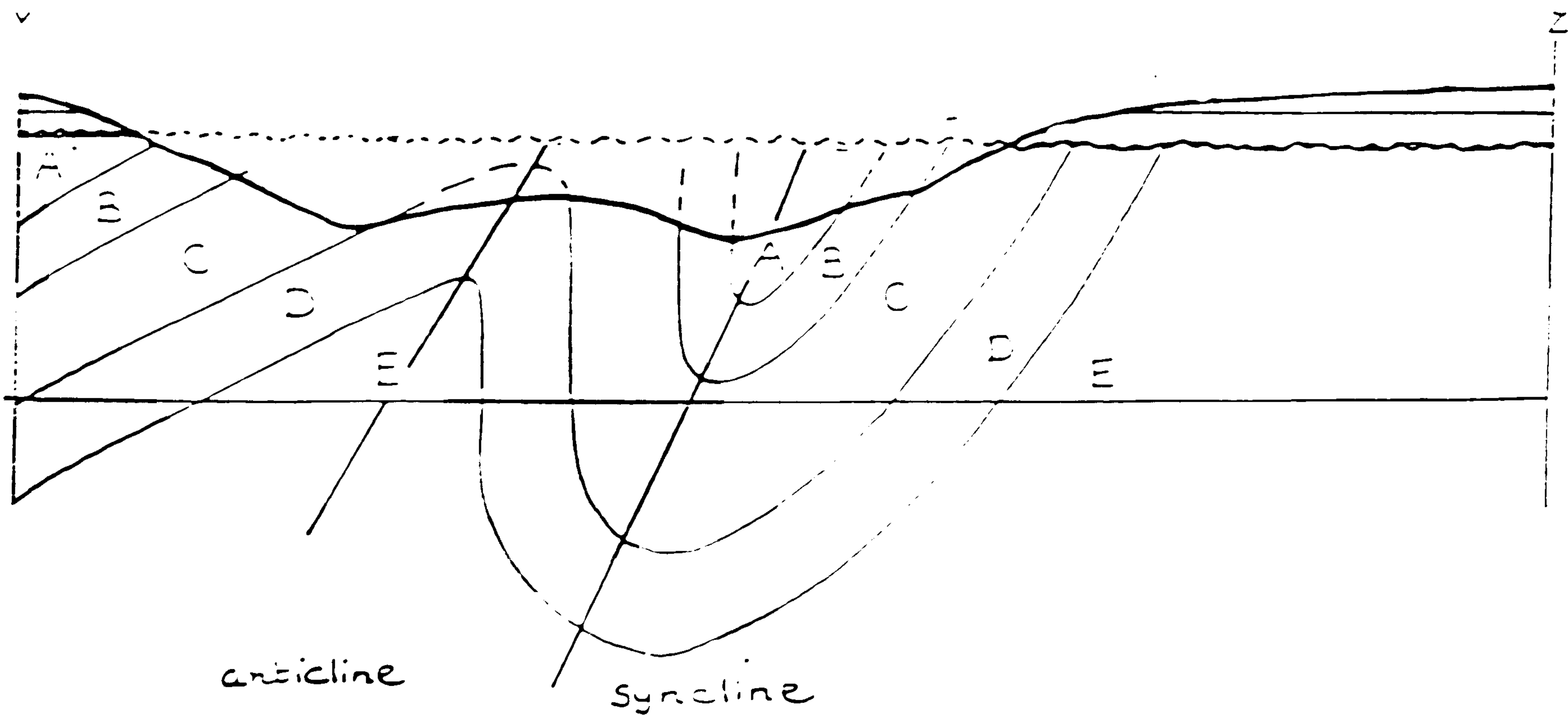
The purpose of this exercise is for you to practice identifying dip direction. Study the cross-section which identifies whether a fold is a synform or antiform.

On the Map provided on the next page, you are to

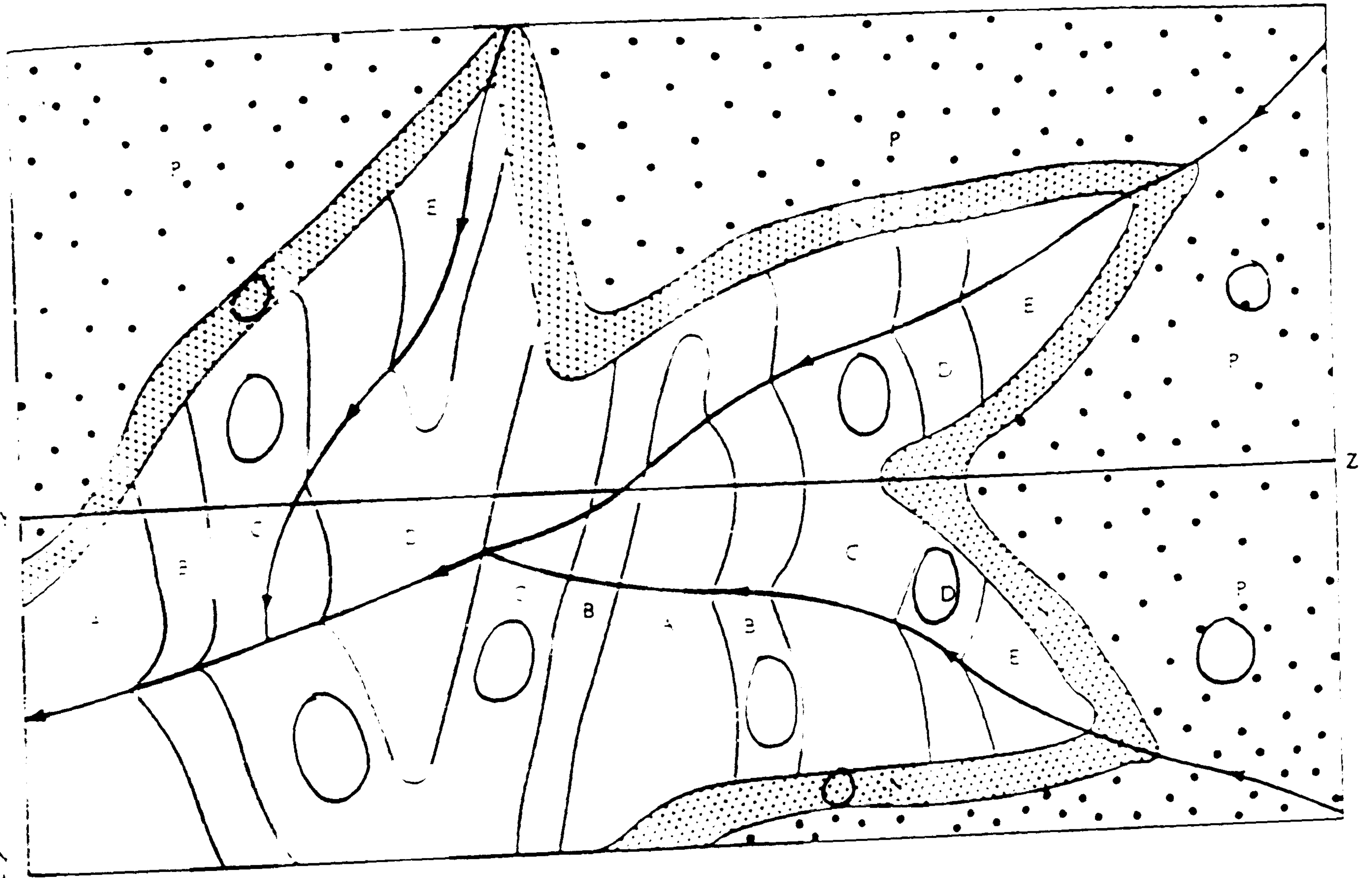
Mark the correct dip directions in the circles provided.

Mark any fold axial planes, using the symbols;

(synform  , antiform  )







100m

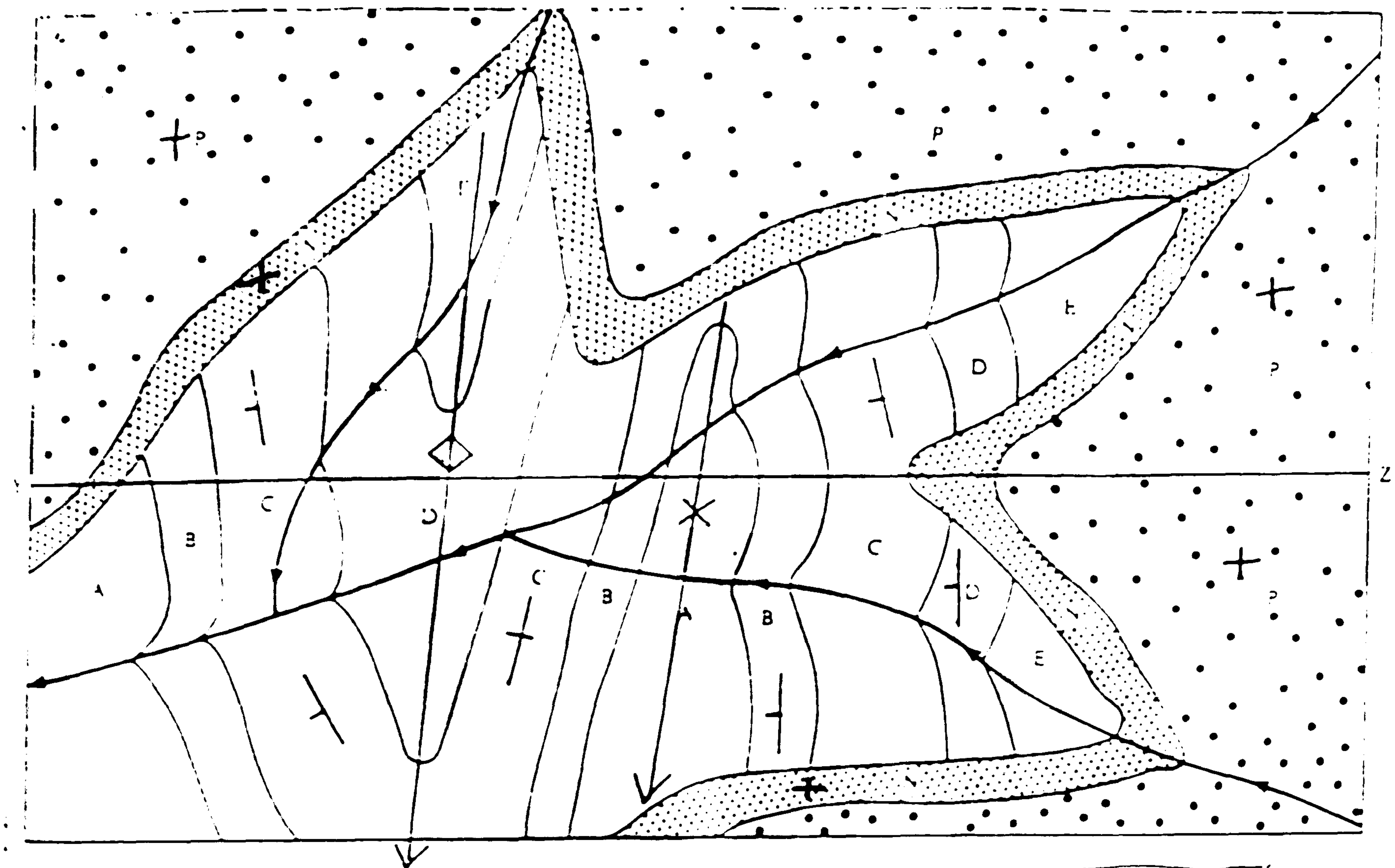


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### 3.4 Feedback

Here is the map view showing one antiform and one synform with the correct dip directions marked.



### 3.4 Summary

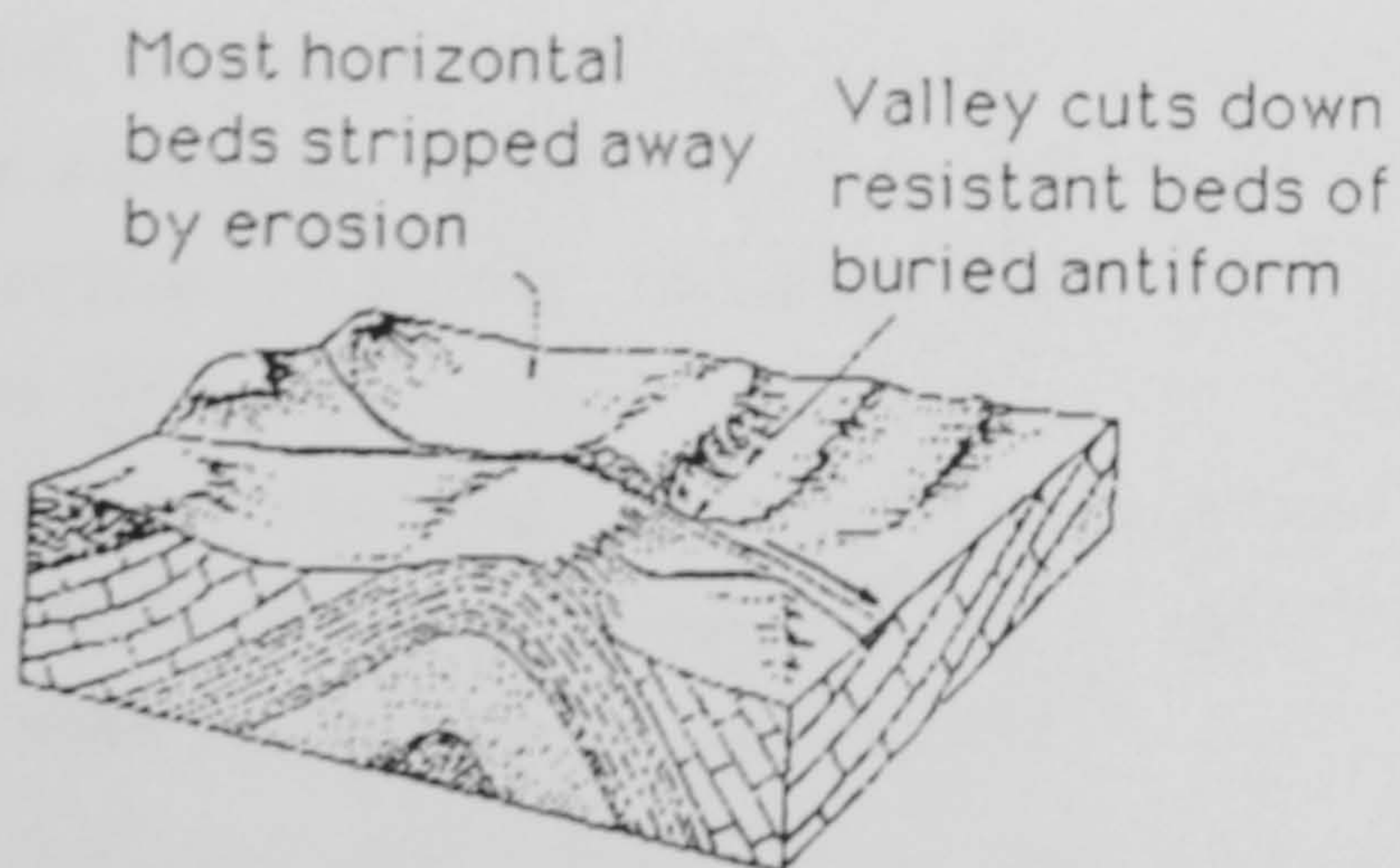
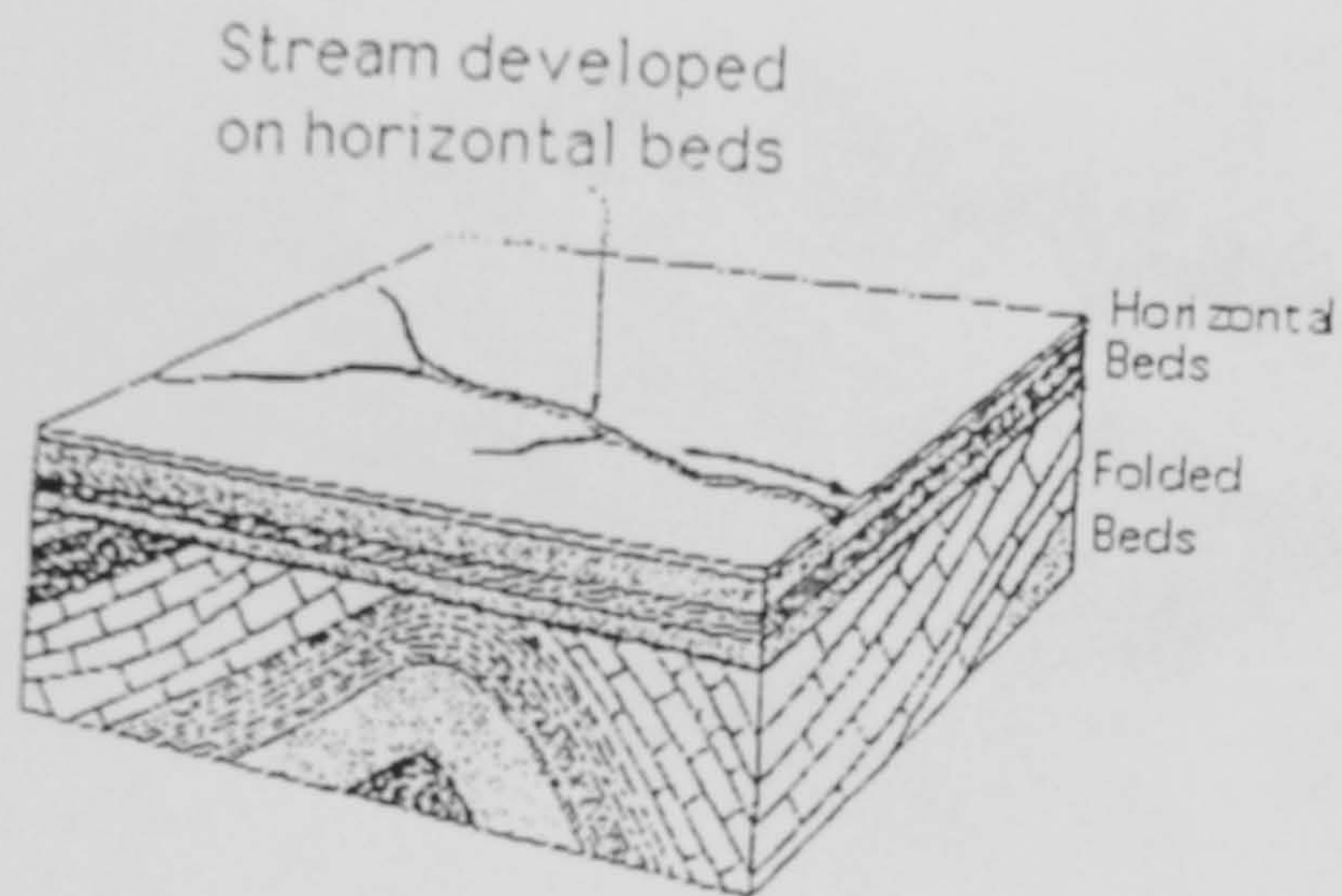
You have now practised determining dip direction from a cross-section view to a map view of the same area appear. As you will remember, another way to determining dip direction is by interpreting V-shapes on a plan view map.



### 3.5 Interpreting V's

#### Introduction

*Present-day* features, such as rivers or streams, do not cause geological sub-structures, rather they are superimposed on them. Their presence can provide clues to help interpret a geological map. As the next illustration shows, a valley on the topography can be superimposed on an antiform underneath.



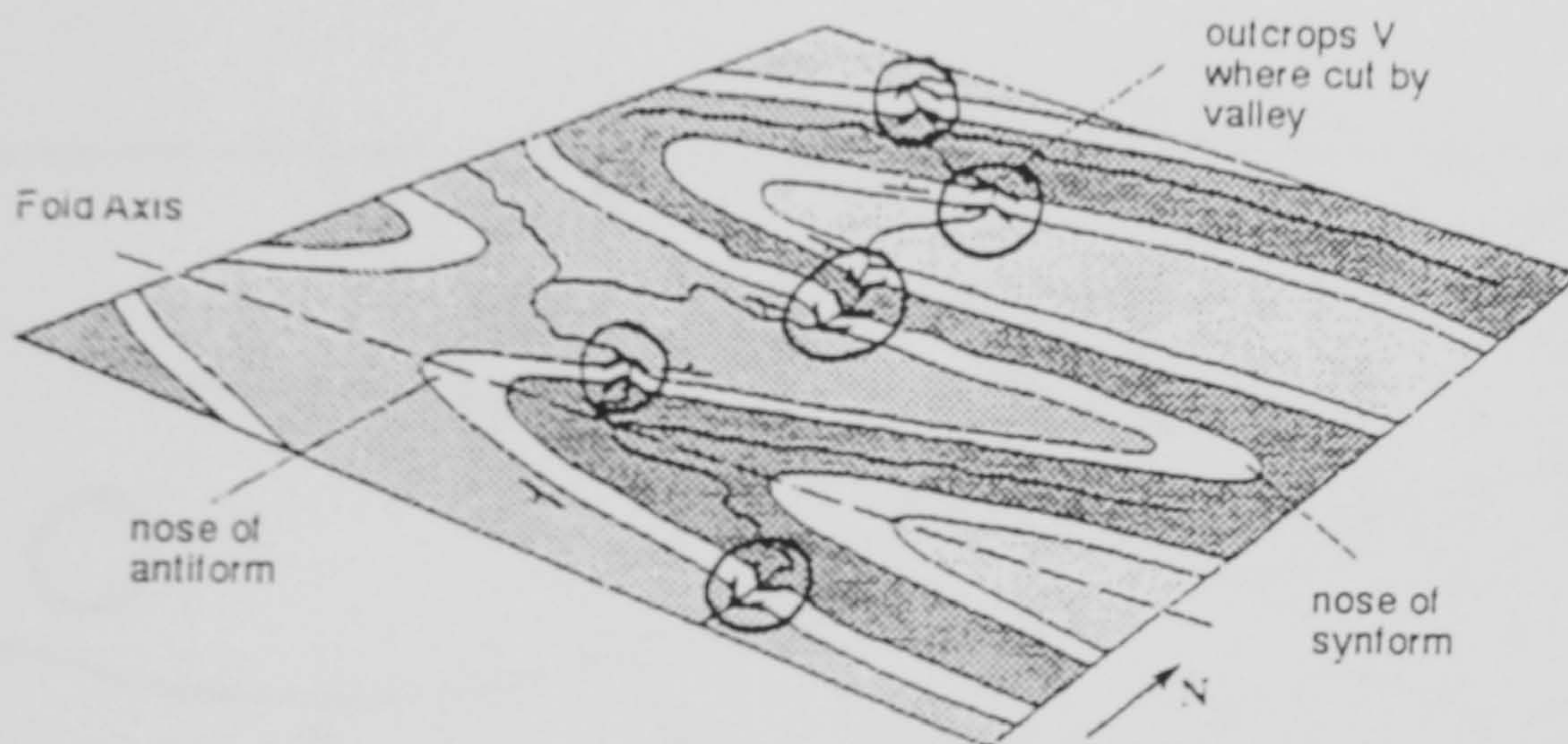
(from Selby, 1968)

V-patterns are useful topographical clues which form on a geological map where a valley or stream cuts in to the rock beds, exposing the direction of the dip of the formations. The way the outcrop patterns V



depends on the dip of the geological surface relative to the topography. Outcrop Vs of dipping strata tend to point in the direction of the dip.

The following diagram shows a synform and antiform which are cut by a valley and stream. Notice the V's are circled.



It is useful to remember that vertical strata do not exhibit any v's on valleys or streams. However, it can be a bit confusing to consider the case of horizontal strata, because when horizontal strata outcrop and are eroded by valleys, they also exhibit V's. The reason for this is that horizontal beds are *parallel* to the topographic contours. However, horizontal beds do not exhibit the same type of repeating wavy patterns on a map view as folded structures.



### 3.6 Learning Exercise 6: Interpreting V's

#### Instructions

Look at the following map. Circle any V-patterns and indicate the dip direction of the outcrops in the circles provided. Label any folds using the following symbols;

Synform 

Antiform 



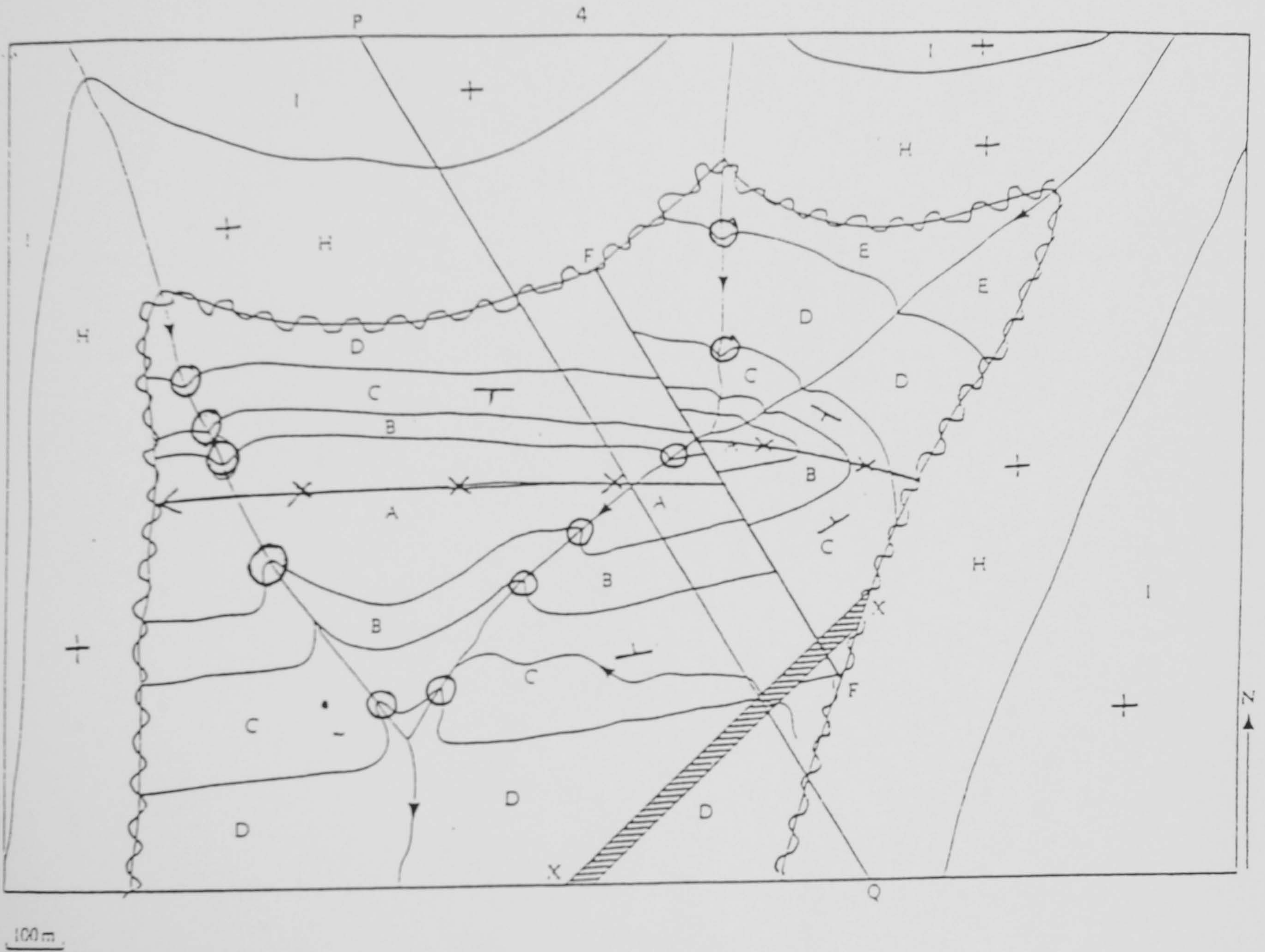


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to complete the exercise.



### 3.6 Feedback

Here is the solution to the map. Notice the circled v's, especially those indicating the synform. On this map as well you will notice an unconformity which separates the older, folded beds, A- E, surrounded by younger, horizontal beds, H and I.





## Summary

In this lesson you have practiced determining dip directions and interpreting v's on maps, as well as consider the continuous nature of erosion on folded geological structures. Thank you for your time. Please ensure that you have written your student identifier on page one.



## **Appendix IV**

### **Pre-and Post-Test Questions for Evaluation Study 1**



Thank you for participating in the study I am carrying out as part of my research. Please put your student identifier and date at the top of the page. All the information is completely confidential, and none of your answers will be seen by anyone but me. I will only write about the results of the study by reporting how ALL the students as a group responded to the materials. No individuals will be identified.

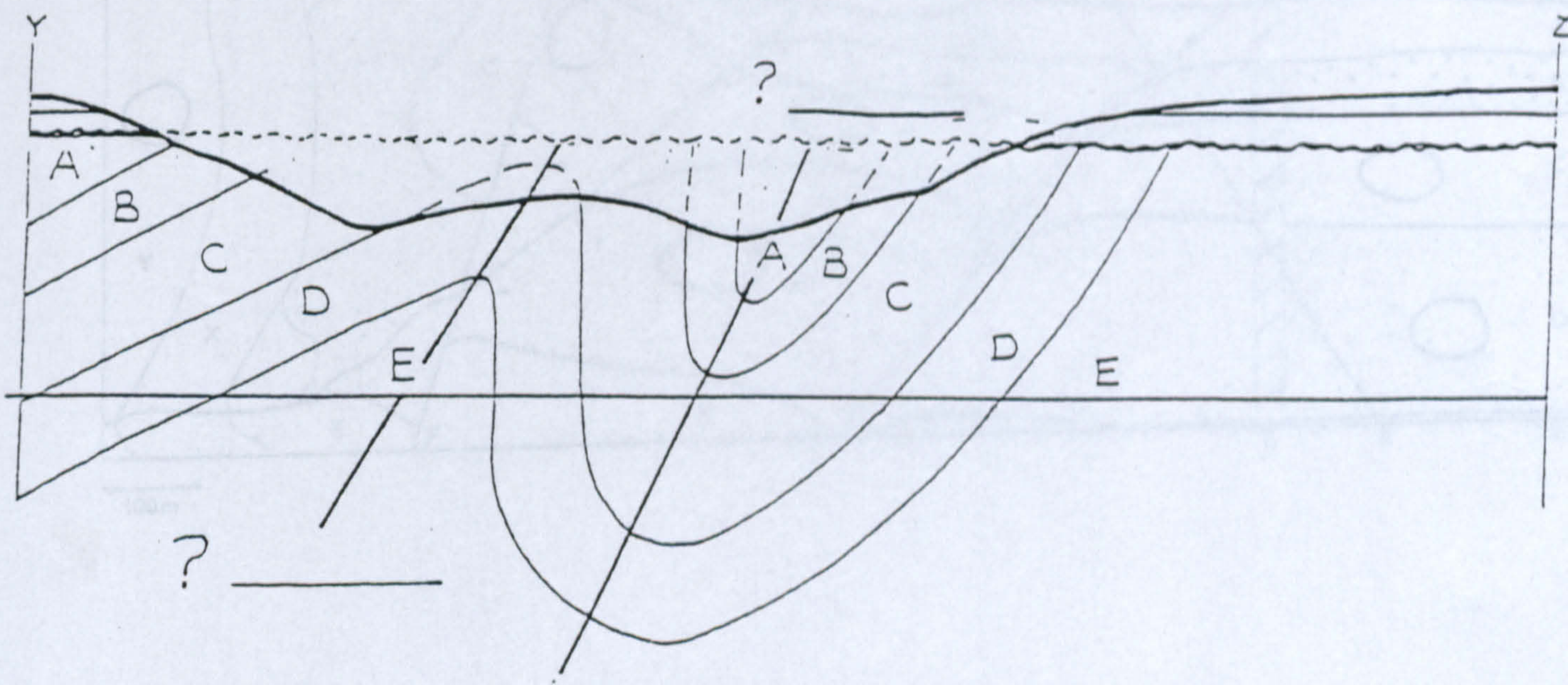
Please answer the following questions as best you can. Don't be concerned about drawing perfect sketches. This test should take approximately 10 minutes to complete.

STUDENT IDENTIFIER:

AGE:

DATE:

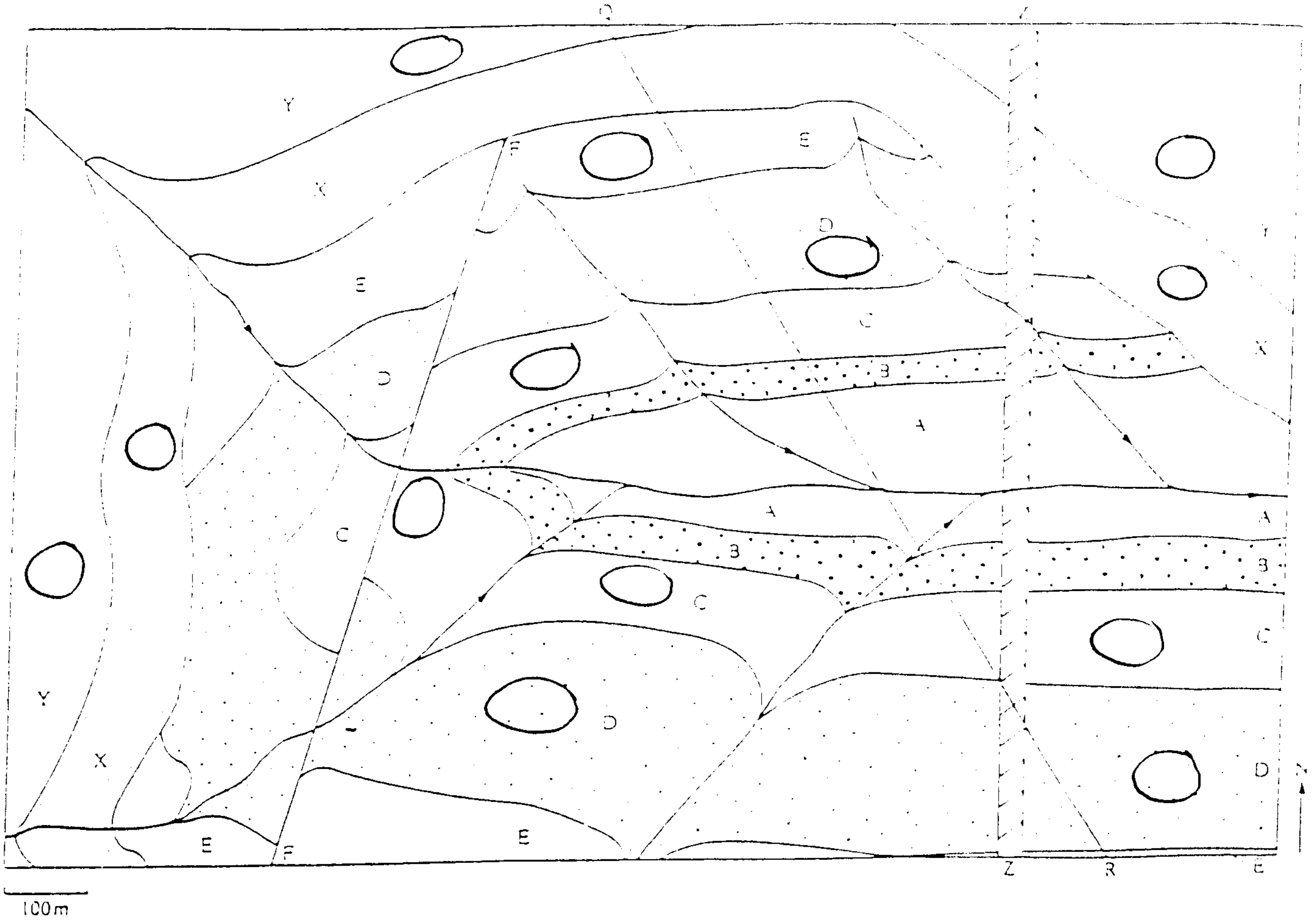
Question 1. Label the formations on the following cross-section in the blank \_\_\_\_\_? provided on the map as either antiform or synform





Question 2. For the following map, mark the strike and dip directions in the circles provided using the following symbols.

- + for horizontal beds
- for dipping beds

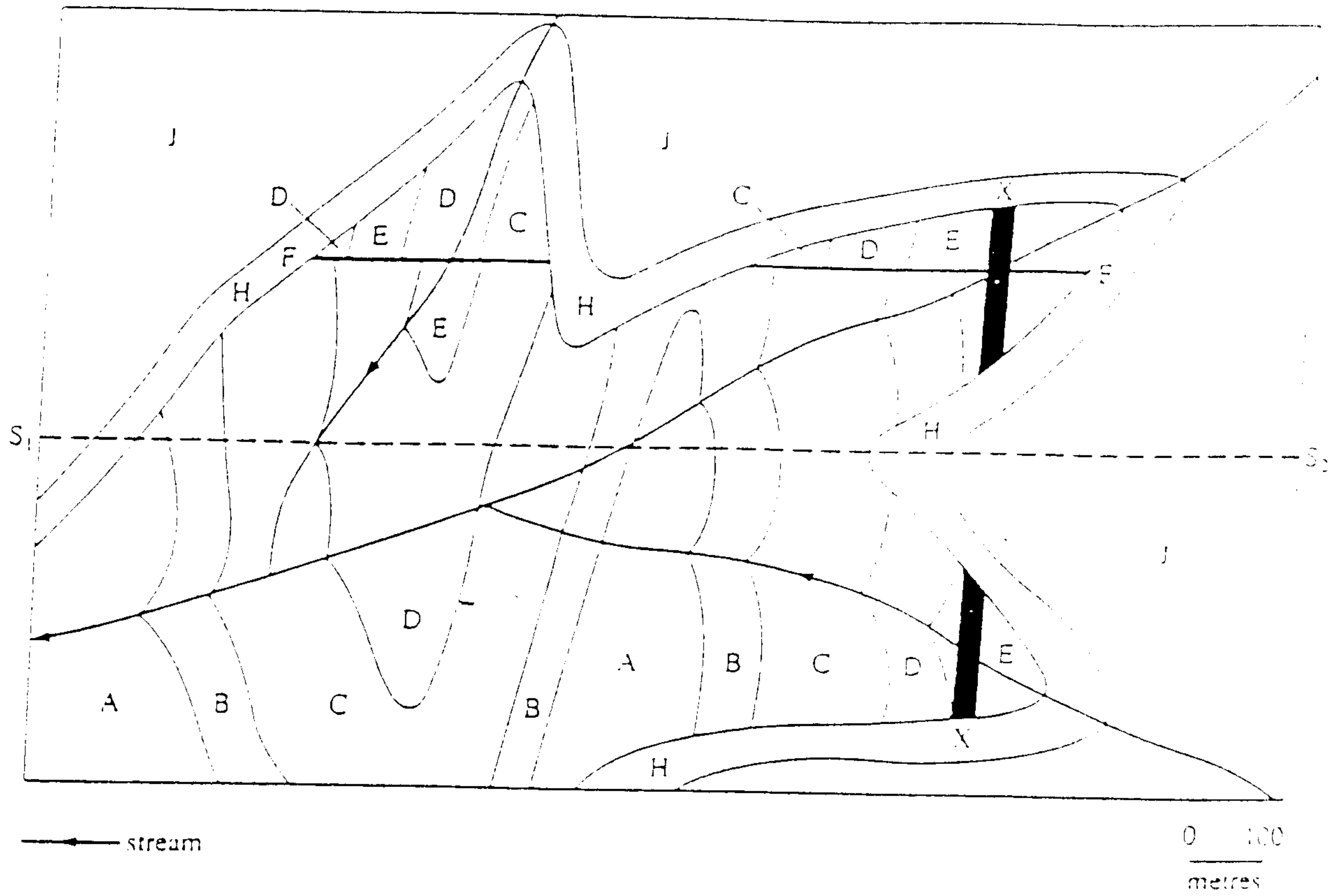




Question 3. On the map provided, circle any V-shapes on the rivers. Mark any fold axial with the following symbols:

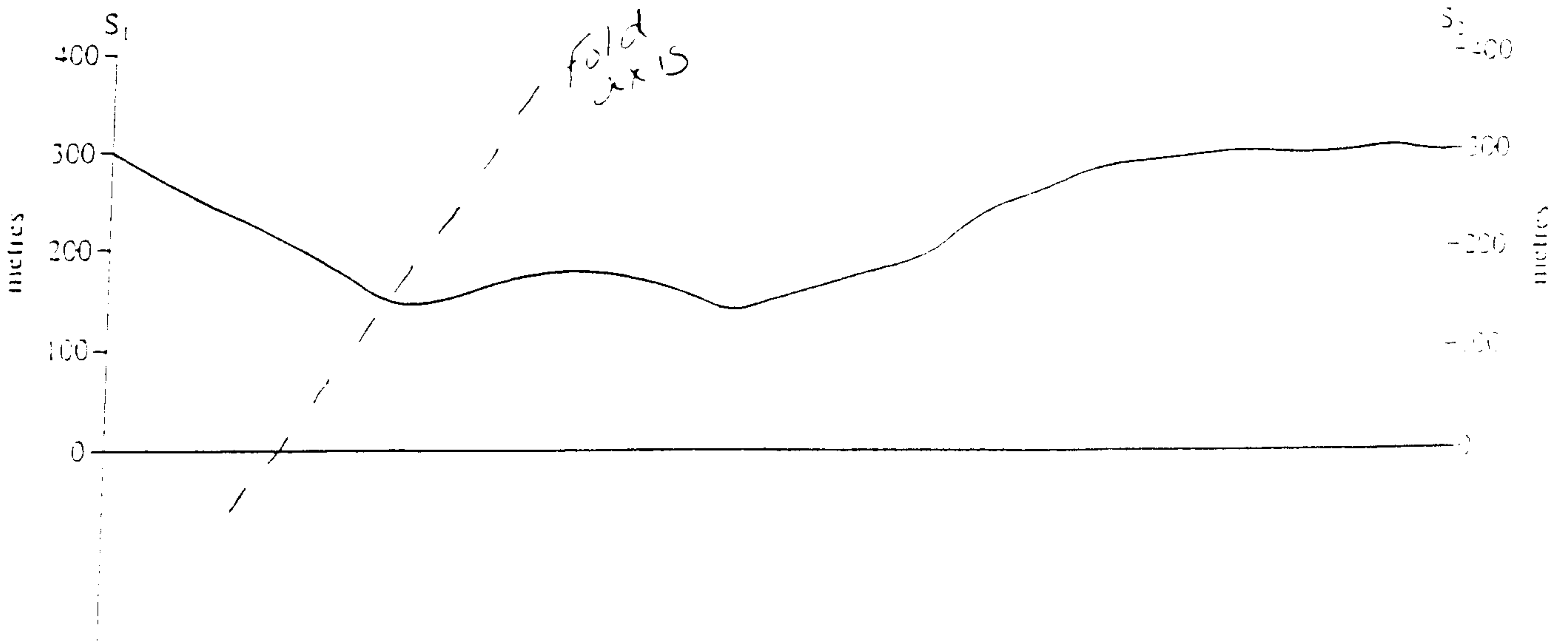
synform 

antiform 



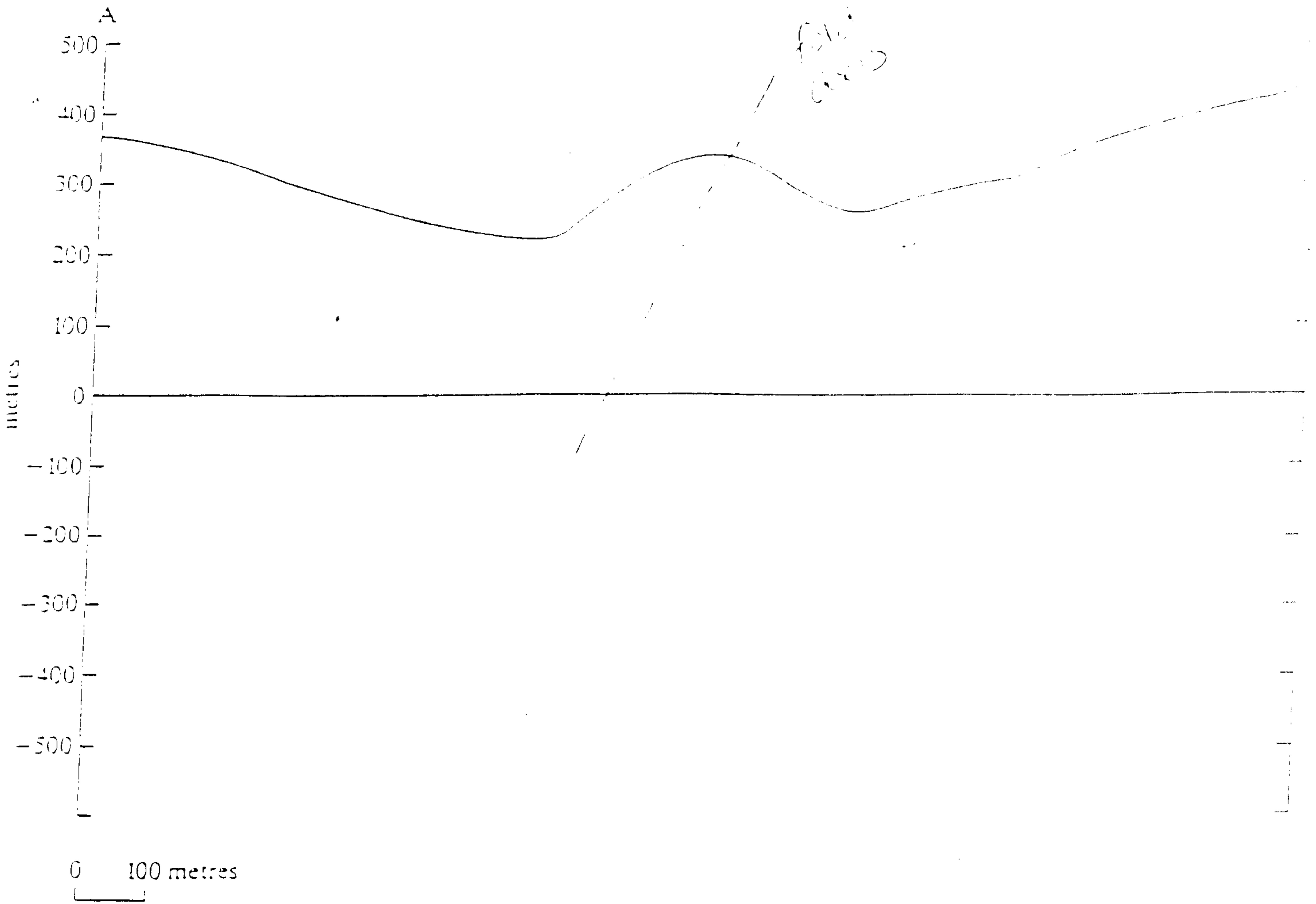


Question 4 Using the following topographic profile, draw a sketch cross-section which illustrates an antiform where there is a valley at the fold axis of the antiform on the topographic profile.





Question 5. Using the following topographic profile, draw a sketch cross-section which illustrates a synform where there is a hill at the fold axis of the synform on the following topographic profile.





## **Appendix V**

### **Questionnaire for Evaluation Study 1 and Evaluation Study 2**



# QUESTIONNAIRE FOR S236 STUDY PARTICIPANTS

**STUDENT IDENTIFIER:**

**DATE:**

Please take a few moments to fill in the following questionnaire about your impressions of the learning materials you have just used. Thank you for your time.

1. What did you like about the materials?

2. What did you NOT like about the materials?

3. Circle any statements that are true for you.

The materials were:

•                      •                      •                      •                      •  
easy                      about right                      difficult

4. Rate the following components of the materials on a five-point scale from 1 very useful to 5 not useful.

	useful			not useful	
a) Exercises	1	2	3	4	5

Is there anything in particular you could comment on about the exercises used in the lesson?



**b) Diagrams**

**useful**                      **not useful**  
1      2      3      4      5

Is there anything in particular you could comment on about the diagrams used in the lesson?

**c) Explanations**

**useful**                      **not useful**  
1      2      3      4      5

Is there anything in particular you could comment on about the explanations in the lesson?

**d) Feedback**

**useful**                      **not useful**  
1      2      3      4      5

Is there anything in particular you could comment on about the feedback in the lesson?



5. Please circle and comment on any of the following statements which are true for you.

The materials:

- **taught me nothing new**
  
- **taught me something new**  
If so, what new ideas did you learn?
  
- **reinforced what I knew**  
If so, what ideas did it reinforce?
  
- **cleared up some things I was struggling with**  
If so, what kinds of things did it clarify?
  
- **caused me to be confused about things**  
If so, what ideas are you confused about?



## **Appendix VI**

### **Pre-Test and Post-Test Mapping Task**



Thank you for participating in the study I am carrying out as part of my research. Please put your student identifier and date at the top of the page. All the information is completely confidential, and none of your answers will be seen by anyone but me. I will only write about the results of the study by reporting how ALL the students as a group responded to the materials. No individuals will be identified.

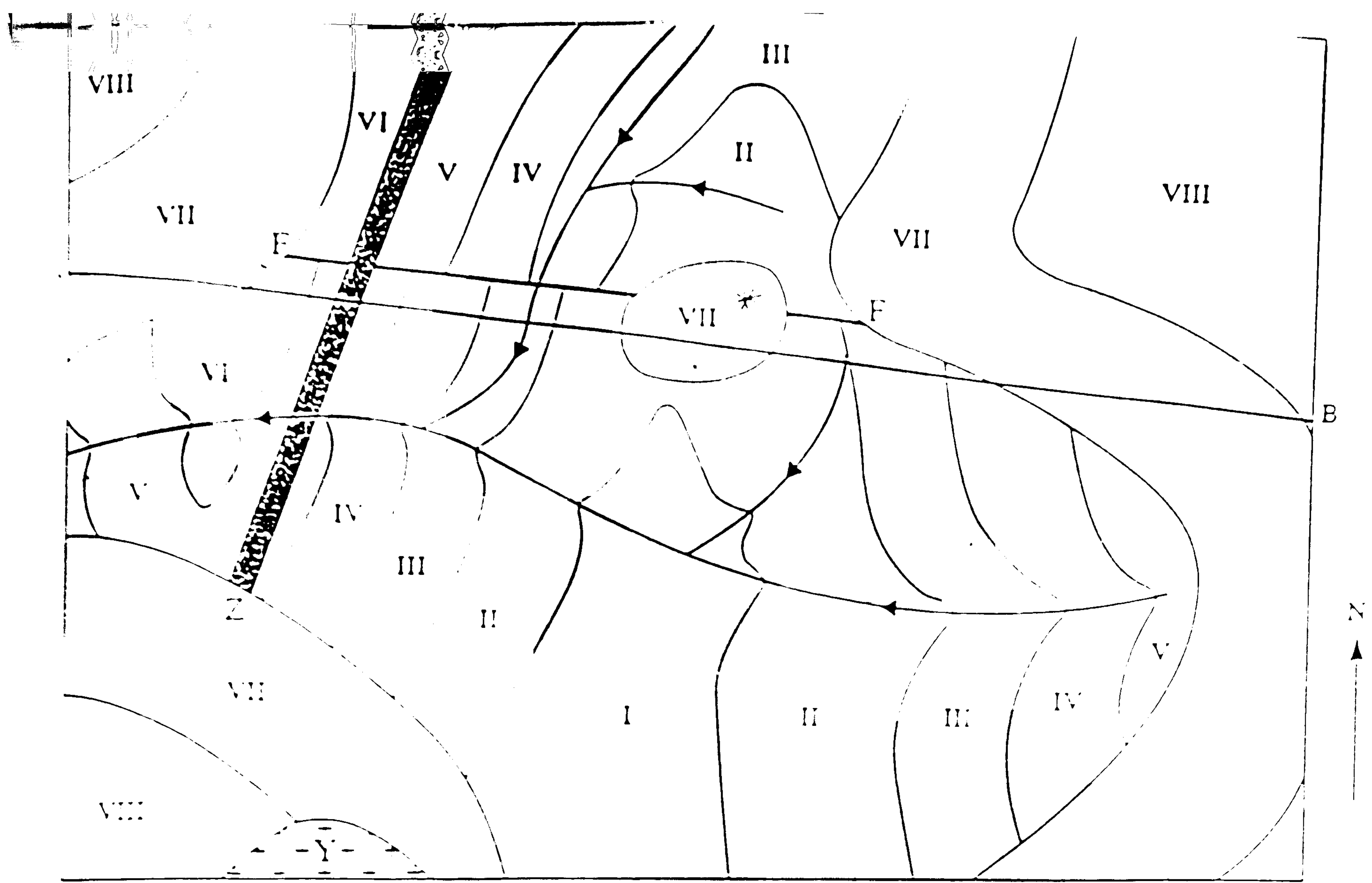
Please answer the following question as best you can. Don't be concerned about drawing perfect sketches. This test should take approximately 10 minutes to complete.

**STUDENT IDENTIFIER:**

**DATE:**

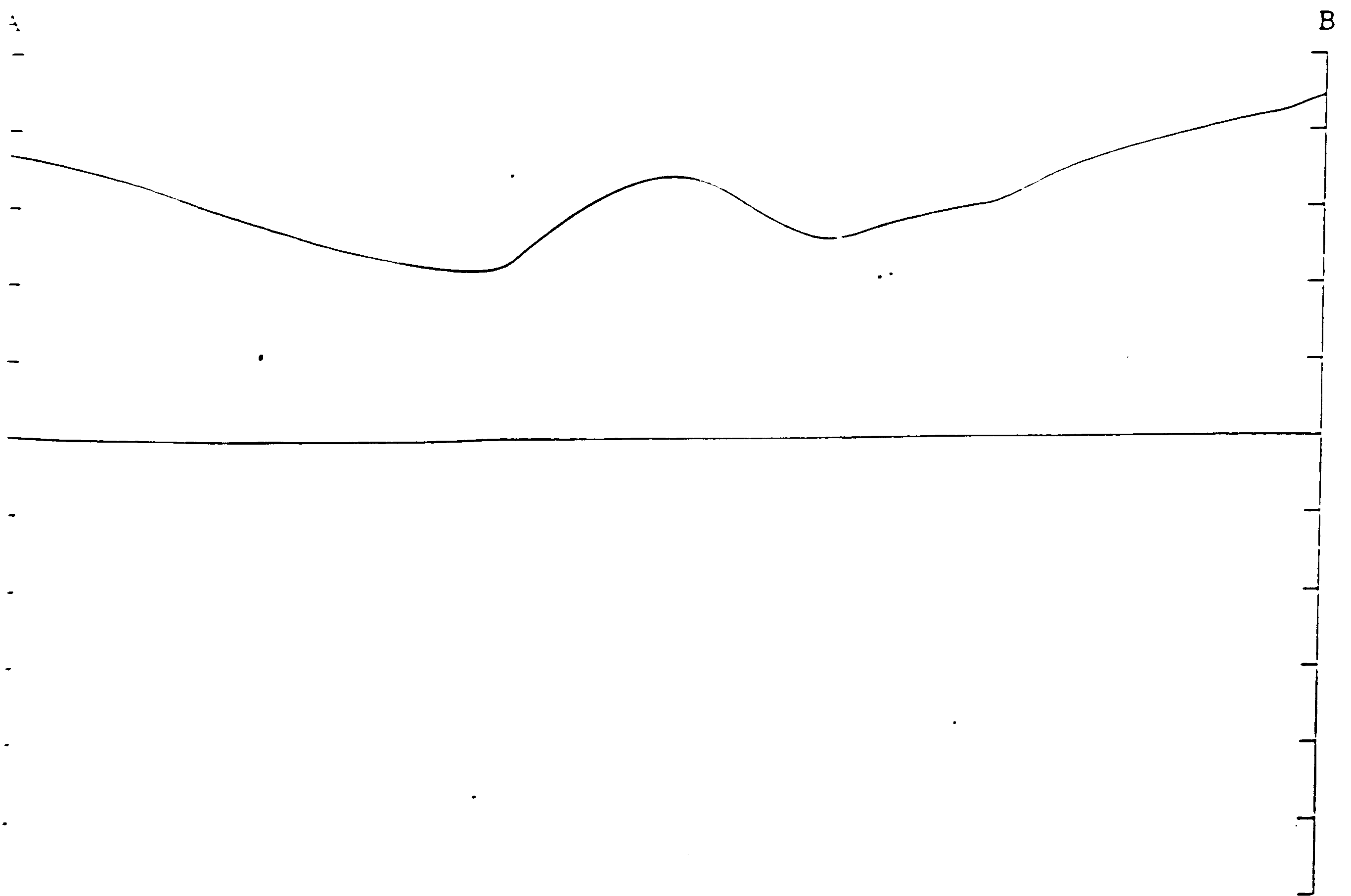
Look carefully at the following map and topographic profile. Make any markings you like on the map indicating dip and strike directions, and folds. Then write a couple of paragraphs explaining how you made the interpretation of the dip directions and types of folds. In your explanation, describe how you visualised the geological structures and any features on the map you used in your interpretation. Your description does not need to include interpretation of the faults or igneous intrusions.





0 100 metres

FIGURE 1 Geological map



100 metres



## **Appendix VII**

### **Phase Diagram Study Interview Questions**



## Questions for Study of Phase Diagrams

1. What does a phase diagram represent to you?
2. What is the significance of phase diagrams in the study of metallurgy?
3. What does the free energy diagram represent to you?



## **Appendix VIII**

### **Phase Diagram Formative Evaluation Instruments**

## 4.1 Pre-test

### Teaching and Learning Technology Programme Materials Science Consortium

#### Pre-Program Questions

Date: 18th July 1994

Teacher: No teacher

Hardware: 486 PC

Program: Use of the Phase Diagram

Institution: Imperial College

Evaluator: Michael W Dobson

Time: As appropriate

Student name(s): As appropriate

Q1. What is a phase? Provide a brief and comprehensive answer, using an example to illustrate if possible.

*The portion of an material system [alloy] whose properties and composition are chemically homogeneous (5a), and which is physically(5b) distinct from other parts of the system. For example, the liquid phase which forms when mixing Silver and Copper at a high temperature is homogeneous and one could not distinguish between the two elements, also the liquid phase is physically distinct from the solid phases of the system (5c).*

Q2) List the three parameters that make up the constitution of an alloy.

*The constitution is a description of what the alloy is made of.*

*The number of phases (5d) of the alloy and what these phases are (5e).*

*The composition of each phase (5f).*

*The proportion of the phases (5g).*

Q3. Why might the constitution of a real alloy in practice differ from that predicted by an equilibrium phase diagram?

*The assumption of an equilibrium phase diagram is that the elements are in equilibrium (5h), this is only possible given unlimited time (5i). Therefore in the real alloy there could be different number of phases (5j), different composition of elements within a phase (5k), and/or different proportion of solid/liquid within a two-phase region (5l). In general the solidus will tend to be lower in the diagram - i.e. solidification will take place at lower temperatures (5m)..*



## 4.2 Post-test questionnaire

[This questionnaire was administered immediately after the post-test (the same as the pre-test above).]

Q6) To what extent do you agree with the following descriptions of the program?

1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree.

*Please circle one*

Easy to operate	1	2	3	4	5
Enjoyable to use	1	2	3	4	5
Provides good exercises	1	2	3	4	5
Provides good feedback	1	2	3	4	5
Helps you learn about phase diagrams	1	2	3	4	5
Fits well with the rest of the course	1	2	3	4	5
Well worth the time spent on it	1	2	3	4	5

*Please add any further comments if you wish*

Q7) This program is meant to help you learn, revise and extend your knowledge of using phase diagrams. Could you please comment on the ways it a) succeeded in this, and b) could have been improved.

a)

b)

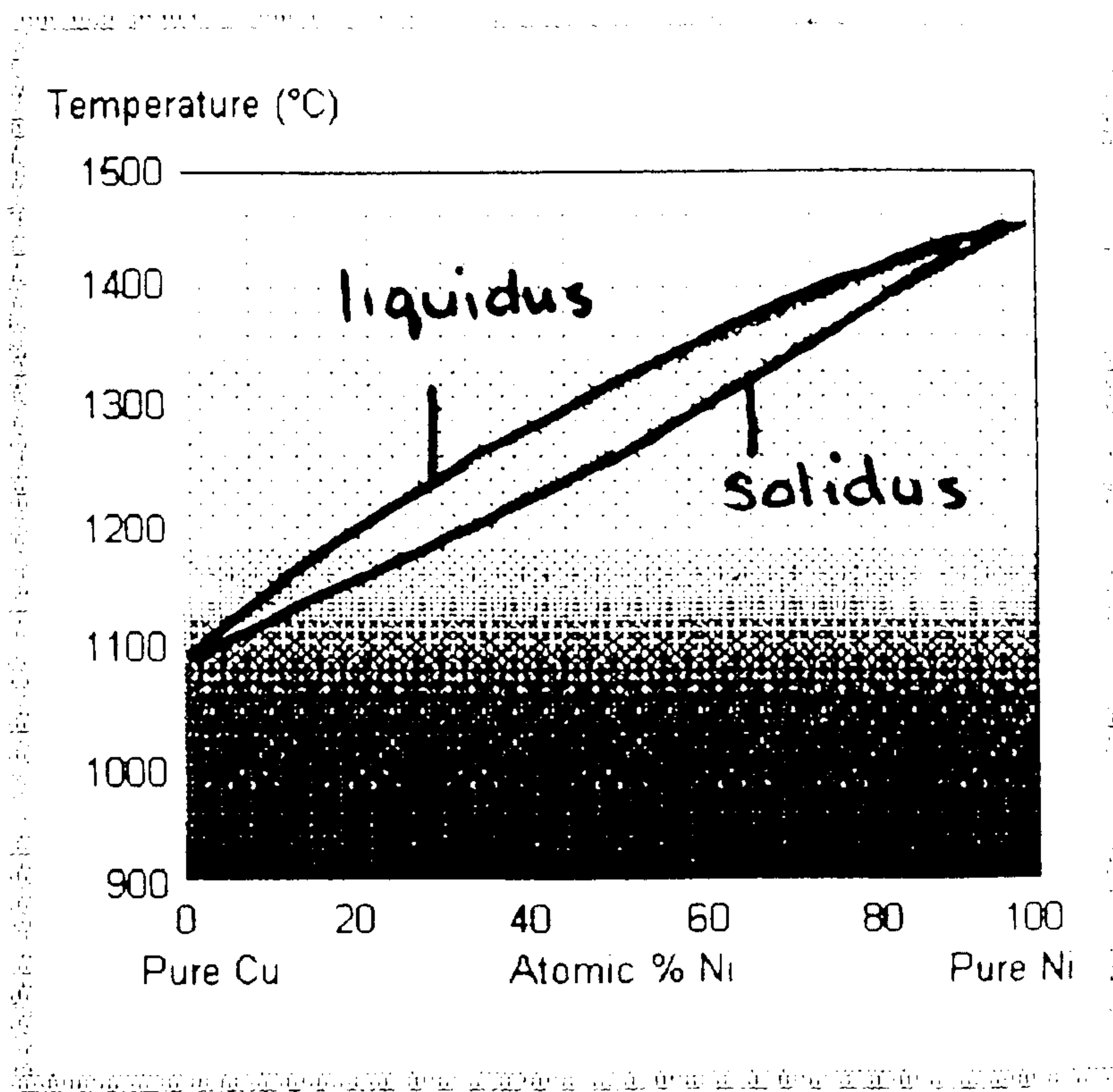
Q8) Would you want to use it again? Please say why, or why not.

Thank you very much for your help. Your comments will be used to improve the program and the way it is used.

Q4. Given the following binary equilibrium phase diagram;

What phase is present above the liquidus line? liquid (5n).

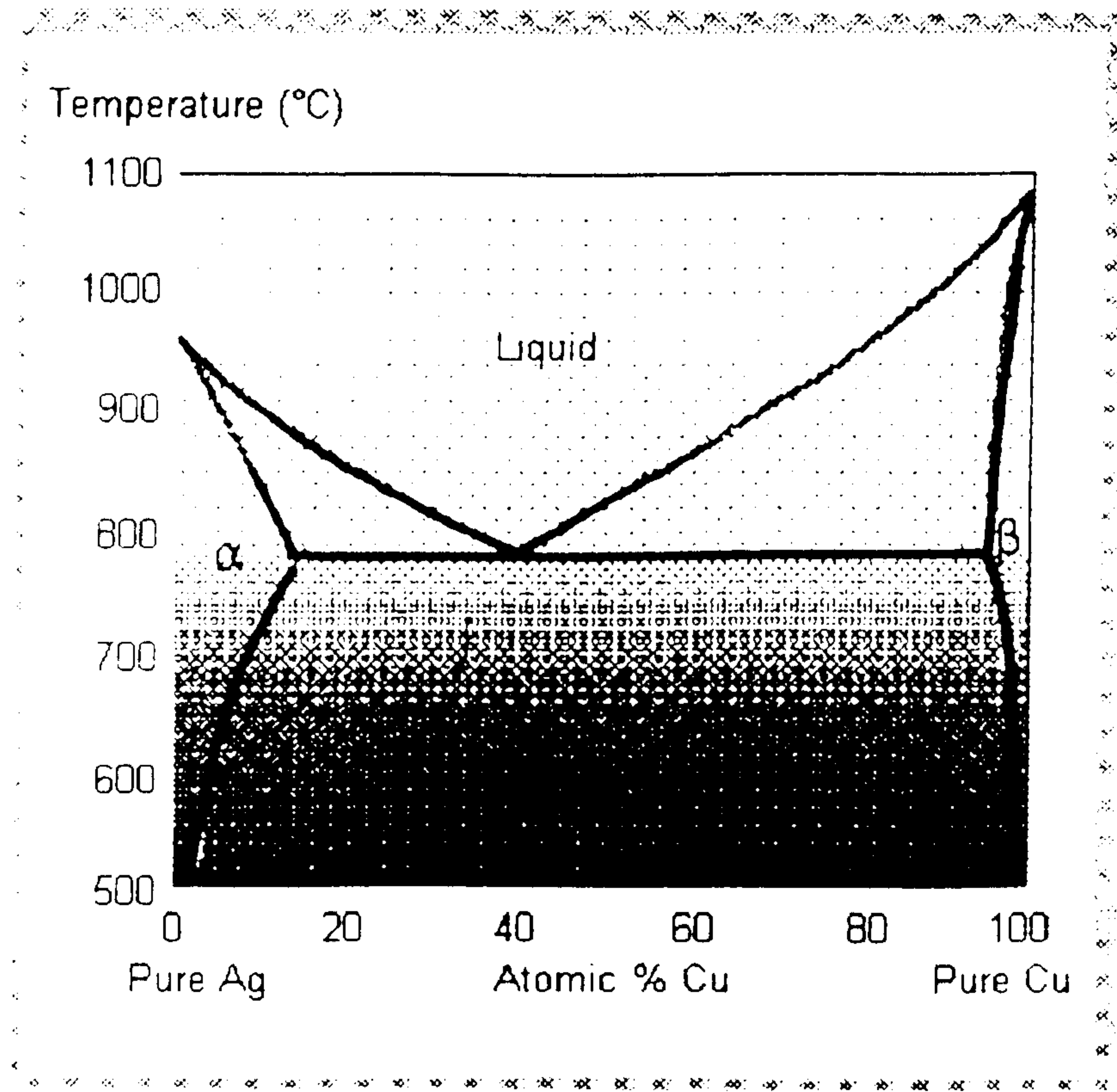
What phase is present below the solidus line? solid (5o).





Look at the following eutectic equilibrium phase diagram for silver (Ag) and Copper (Cu).

Complete the labelling of the phase regions



They should have

a + liquid (5p), b + liquid (5q) and a + b (5r).  
*[points only given for correct label in correct place]*

What is (approximately) the maximum solubility of Cu in Ag? about 14% (5s).

What is (approximately) the eutectic temperature of this system? about 785 degrees (5t).