PREFACE

This manual is prepared as an accompaniment to the author's 2-3 day workshop course on structural geology. In spite of this role, it is written to be read as a stand alone text, and is aimed at complementing the courses by providing a resource for further explanation, private study and reference. The text broadly follows the oral presentation and utilises many of the same diagrams. However, most of the examples and case histories – a feature of the course – have been omitted.

Professional working in the metal mining and exploration industry (the "explorationists" of the title) need a wide range of skills and knowledge. Of all these skills, one of the most valuable is the ability to collect and interpret field geological data - derived from ground observation, drilling and remote sensing – in order to produce testable models of economic mineralisation. The geology speciality that allows this to be done, above all others, is structural geology. This course aims to provide that specialist knowledge.

This consideration has determined the following features of the course:

- Theory is essential, but is kept to a minimum and presented in a graphical rather than a mathematical way.

- Structures related to brittle and brittle/ductile deformation (essentially: shallow and mid-level faults) feature far more prominently than other structures in controls on the distribution and shape of ore. For this reason, discussion of brittle deformation features more prominently in this text than in most academic treatment of structural geology.

- Wherever possible, examples are given from mining camps or mineral exploration projects and aim to show the controlling role of structure upon economic or potentially economic mineralisation.

- As an essential part of the course, participants will work on exercise problems that are designed to illustrate typical structures. The exercises will help develop interpretation skills in situations that an explorer might encounter in real exploration projects.

There is no magic recipe for finding ore bodies and no readymade solutions are offered here. However, it is hoped that anyone taking this course will acquire some knowledge and skills that will be of value in their professional life.

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1. INTRODUCTION

This aim of this course is to show the various ways in which structure controls the location, size, style, shape and attitude of ore bodies. It will demonstrate, with examples from real exploration programs and real ore bodies, how geologists looking for ore or working with ore bodies can use structure to help them find and, once found, define ore.

Structural theory attempts to answer ***why*** structures form and ***why*** they have their characteristic size, attitude and appearance. Exploration geologists are not primarily concerned with theory. Their job is to find ore bodies: to answer questions that begin with "*where?*" or "*how much?*" rather than "*why?*" Can we safely leave *"why"* to the academics? *W*hat is the point of learning the theory? There are three good reasons:

- It is not generally possible to answer "where" without first considering "why". And to answer "why" questions an understanding of theory is essential.
- Not every rock appearance that might be encountered in the field can be defined in advance, and the structure that a geologist actually sees in outcrop or drill core may not much resemble the diagram in the textbook or ideal specimen in the laboratory. Knowledge of theory enables the geologist to work out new relationships or unusual presentations when he comes across them in the field.
- By presenting some basic structural theory, I hope to demonstrate that structural geologists are not in the business of vague arm-waving empirical relationships (well, only sometimes!) – but have rigorous science and understanding behind them – probably to a greater extent than in many other geology disciplines.

This course therefore begins with the basic theory of how rocks deform. The theory is founded in mathematics, but few beside professional mathematicians are comfortable with long equations on the page. Fortunately, the mathematics lends itself to graphical presentation - simple and easily remembered diagrams that can provide visual models of the processes involved. This is the route that I will take in my explanations. If you want to explore the mathematical aspects of structural geology, I offer a brief treatment in Appendix A. More comprehensive coverage will be found in the books by Jaeger (1969) & Ramsay & Huber (1987).

First, let us establish the scope of what is to come by attempting to answer a few basic questions.

What Is Structural Geology?

The recognition, description, classifying, understanding and use of rock discontinuity (structures)

- Some examples of structures are: bedding planes, faults, folds, fractures, joints, stylolites, cleavage, lineation, boudins, fibres, slickenlines, foliations, pressure shadows, veins, breccias, intrusive contacts. These can occur at all scales from microscopic to map scale.

- The study of structures occurring at continental or crustal scale is often called tectonics. Tectonics is simply structure writ large.

What Causes Structure?

- Structures form because of stress acting upon rocks. This may happen either at the time the rocks are formed and/or at any subsequent stage.

- All the stress acting upon rocks is attributable, either directly or indirectly, to two fundamental earth forces: ***gravity and heat***.

- The major effect of gravity is the progressive increase with depth of lithostatic and hydrostatic pressure.

- The ultimate source of heat in the earth is the radioactive decay of minerals

- Gravity and heat together drive the movements of the earth's crustal plates.

What Value does Structure have for the Explorationist?

- An accumulation of minerals capable of being mined at a profit is called ***ore***.

- Such accumulations are rare and result from an unusual combination of factors acting within a localised volume of rock.

- The key factors controlling ore formation are localised strong gradients in the value of the physical and chemical parameters of a rock body. Common gradients are those of temperature, pressure, ph or the concentration in solution of CO_2, sulphur, iron, chlorine and so on.

- Under the right conditions, these gradients act as a valve to concentrate metallic elements from a more dilute background source.

- The most common reason for localised physical and chemical gradients in a rock mass are the structures which are forming within it.

- Ore bodies most often form at the same time as the structures that host them. The size, style, geometry and attitude of these ore bodies thus reflect that of the host structure. Understanding the structure of a body of rock therefore enables definition of the shape and attitude of any ore body that lies within it.

- The good news is that ***structures are inherently predictable.*** Understanding, defining and predicting structure, can lead to prediction of ore.

What is the Link between Structural geology and Mapping?

The criteria for finding ore deposits are not to be found in the laboratory - they are out there in the field; in outcrop in drill core or drill cuttings; waiting to be observed.

Observation and interpretation are done at the same time. ***Observation drives and controls interpretation: interpretation drives and controls observation in an iterative process.*** The most powerful available tool that enables this to be done is the geological map and the geological section.

Geological maps are graphical, analog presentations of structures observed at mesoscopic and macroscopic scale. .

Our brains are analog processors. Structural data is much more readily understood when it is presented in a graphical way - as a map, section, stereographic plot or block diagram. Recording structure as lists of numbers in a database is generally a futile exercise.

All geological maps are structural maps.

What are Fractals?

Small structures seen in outcrop or thin section can be used as a model to interpret much larger structures occurring at map-scale that cannot be directly observed.

This relationship, where the **style of small structures reflects that of large structures** has been long known to geologists as ***Pumpelly's Rule*** (Pumpelly, 1894). Other sciences have recently caught up with geologists and now this relationship is widely known. Indeed it is seen as a particular example of chaos theory and bears the jaw-cracking name of ***scale-dependent self-similarity***. The relationship is also sometimes called **fractal** – short for **fractal dimension**.

Pumpelly's Rule is invaluable in helping geologists to unravel large-scale structure,