GEOLOGICAL SOCIETY OF LONDON HANDBOOK

THE MAPPING OF GEOLOGICAL STRUCTURES

KEN McCLAY

MAP SYMBOLS

GENERAL SYMBOLS

STRUCTURE	Observed Lithological Boundary	Boundary Position Uncertain	Boundary Position Infered	Outline of Outcrop with Locality Number	Younging Direction	Morain Ridge	Break of Slope	Alluvium Boundary
MAP SYMBOL				126	or			

PLANAR STRUCTURES

STRUCTURE	Bedding	Overturned Bedding	First Cleavage	Second Cleavage	Minor Fold Axial Plane (phase 1)	Minor Fold Axial Plane (phase 2)	Joints (set 1)	Joints (set 2)
TECTONIC SYMBOL	S_0	S_0	S_1	S_2	F_1 AP	F_2 AP	J_1	J_2
MAP SYMBOL	30—110	30—110	60—110	45—115	60—110	45—115	1 55—115	2 30—115

FOLD STRUCTURES

STRUCTURE	Syncline with Dip Direction of Axial Plane	Anticline with Amount and Direction of Plunge	Synform	Antiform	Overturned Syncline	Overturned Anticline		
MAP SYMBOL	45—150	15-041						

FAULT STRUCTURES

STRUCTURE	Extensional Fault High Angle	Extensional Fault Low Angle	Contractional Fault High Angle	Contractional Fault Low Angle	Wrench Fault	Shear Zone		
TECTONIC SYMBOL	E Fault N Fault	E Fault	C Fault R Fault	C Fault T Fault	W Fault	S Z		
MAP SYMBOL	U D 70—150	U D 20—145	D U 65—165	D U 15—160	90—160	90—155		

LINEAR STRUCTURES

STRUCTURE	Bedding/ Cleavage(S1) Intersection	Cleavage(S1) Cleavage(S2) Intersection	Mineral Stretching Lineation on S1	Minor Fold Axis (phase1)	Minor Fold Axis (phase2)	M Fold Axis	Z Fold Axis	S Fold Axis
TECTONIC SYMBOL	L_1	L_2	ML	MF_1A	MF_2A	M-MF_1 A	Z-MF_1 A	S-MF_1 A
MAP SYMBOL	10–050	15-055	15-060 ML	45-050	35-051	50-050 M	40-045 Z	56—045 S

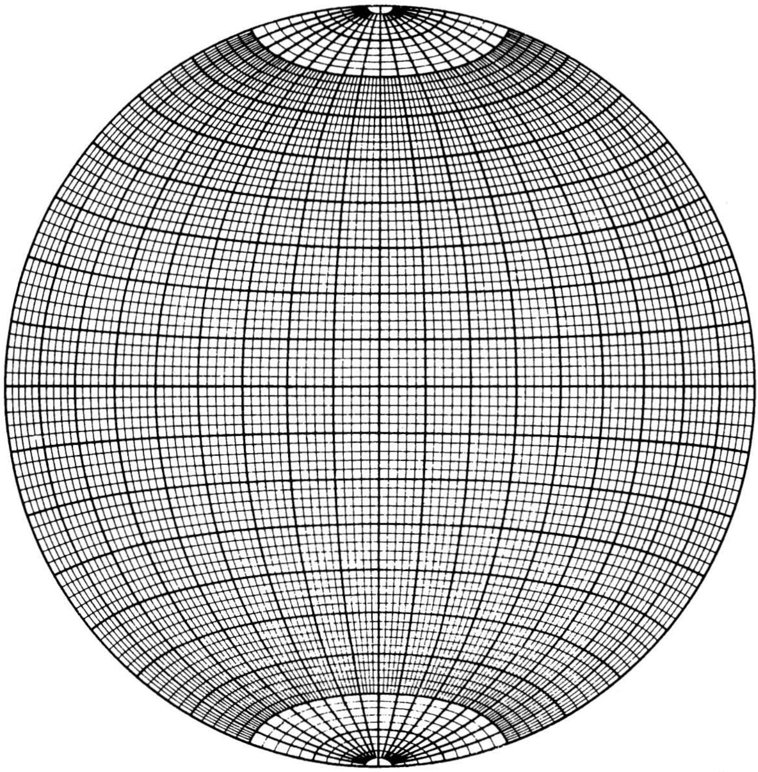

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Fig. 3.9 & Fig. 3.10: BELL, A. M., (1981), *Journal of Structural Geology,* 3, 197–202. Oxford, Pergamon.
Fig. 6.23b: RAMSAY, J. G., (1980). *Journal of Structural Geology,* 2, 83–99, Oxford, Pergamon.
Table 6.4: SIBSON, R. H., (1977). *Journal of the Geological Society of London,* 133, 191–214. Oxford, Blackwells.
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1
Introduction

1.1 Objectives

This book is designed as a basic guide to the field mapping and interpretation of geological structures. Emphasis is placed upon the identification of structures and the systematic recording of structural data, as both should be a fundamental part of any mapping programme. The identification and description of structures, together with an understanding of their development, i.e. their movement patterns (*Kinematic analysis*) and an appreciation of the forces and stresses responsible for them (*Dynamic analysis*) are extremely useful for interpreting particular structures, and for knowing what geometry to expect whilst mapping in a particular terrane.

Structural data cannot be recorded or used in a vacuum. They must be accompanied by full lithological, sedimentological, petrological and palaeontological descriptions for their complete interpretation.

The following aspects are emphasised in this Handbook;

1 Recognition of structures.
2 What to measure and what to describe.
3 How to analyse the data collected.
4 How to interpret the data and incorporate it into the stratigraphy, interpretation and regional syntheses for an area.

In all cases emphasis is placed upon systematic field observations, accurate measurements of the orientations of structural elements, careful recording of the data in the field notebook, sketching and photographing the structures, and analysis in the field using the stereographic projection. Above all, structural geology requires the appreciation of the three-dimensional nature of structures. Think in 3D and learn to extend your view of structures above and below the map sheet.

1.2 Fieldwork

The importance of careful, accurate and systematic fieldwork cannot be overemphasised. Basic geologic mapping techniques are described in Barnes (1981), and the field descriptions of sedimentary, metamorphic and igneous rocks are outlined in the companion Handbooks by Tucker (1982), Fry (1984), and Thorpe and Brown (1985) respectively.

This Handbook describes the field techniques for mapping geological structures and for the identification and mapping of particular types of structure. It also gives a brief summary of the interpretation and analysis of structures.

Remember the following points:

1 Accurate measurement, observation and recording of all structural elements is essential. Avoid data selection in the field, otherwise you may find that upon further interpretation in the laboratory, you have failed to measure a key structural feature.
2 Carry out an ongoing interpretation whilst in the field (draw sketch cross-sections and maps). This will help you recognise key areas where further work may be necessary. Your interpretation will be governed by your experience and knowledge of regional structure, *but only accurate and well-recorded data will have a permanent value and permit continuous reinterpretation.*
3 Data should always be plotted on maps and cross-sections whilst in the field. Only in these circumstances can an effective, ongoing interpretation be achieved.
4 Structural data must be collected in conjunction with other lithological, petrological and palaeontological data.

Conduct and safety in the field

Fieldwork frequently puts geologists in hazardous situations. Structural geologists commonly work in rugged and exposed terrain where 3D exposure is good. Be safety conscious and aware of the possible dangers, particularly from loose rock underfoot, and from rock falls. Barnes (1981) outlines fieldwork safety, and in addition to reading this the reader should also consult the safety checklist on p. 16 of this Handbook before commencing fieldwork. Always carry out fieldwork in compliance with the Geologists' Association Code of Conduct (see Barnes, 1981).

1.3 Tectonic and structural regimes

It is beyond the scope of this Handbook to describe regional structural relationships in detail, but it is useful to identify the dominant features associated with particular tectonic settings, as they provide a useful guide to the structures that may be found whilst mapping (Table 1.1). Characteristic families of structures may be expected to occur in a particular environment, e.g. shallow thrust faults and parallel folding in frontal regions of foreland fold and thrust belts, and this knowledge can greatly aid any ongoing interpretation. Table 1.1 is neither exhaustive nor exclusive in its contents and you should always be prepared for other structures to occur and record all the structural information from the outcrops in your mapping area.

Table 1.1 Structures associated with particular tectonic regimes. (Cont'd on p. 4 and p. 5)

	INTRA PLATE REGIMES			
	Passive continental margins (Atlantic type).	**Continental rift zones**	**Intra-plate strike-slip zones**	**Intra-plate fold and fault belts.**
Major structural elements	Extensional (normal) faulting. Syndepositional tectonics, Salt tectonics.	Extensional (normal) faulting. Strike-slip systems linking extensional faults.	Major fault systems, associated en-echelon folding. Secondary extensional and contractional faulting along curved, overlapping fault systems.	Variable folding & thrusting. Extensional faulting associated with regional uplift.
Metamorphism	None to burial metamorphism. Compaction due to burial.	Hydrothermal systems and volcanic activity, elevated heat flow. Dynamic metamorphism associated with faults, cataclasites — mylonites.	Generally low grade.	Variable — to granulite facies. Development of fault rocks, cataclasites — mylonites along active fault zones.
Examples	Eastern U.S.A. continental margin, West African continental margin.	North Sea Basin. East African Rift System.	Northern Rocky Mountain Trench — Tintina Fault System, Canada.	Basin and Range, U.S.A.

Table 1.1 (cont'd) Structures associated with particular tectonic regimes.

	ACTIVE PLATE MARGIN REGIMES			
	Constructive	**Conservative**	**Destructive**	**Collision**
	Mid-ocean ridge systems, and marginal basin spreading systems	Major strike-slip fault systems	Island arc or continental margin arc systems	Continent–continent or continent–island arc collision
Major structural elements	Extensional (normal) fault systems, major strike-slip (transform) fault systems	Strike-slip fault systems local extension (normal) and contractional (reverse or thrust) fault systems. Local folding — typically en-echelon patterns. Development of pull-apart basins along fault system.	Subduction complexes — Fold and thrust belts — uplifted volcanic arcs — Fore-arc basins, oblique subduction — strike-slip systems. *Subduction complexes* — Contractional (thrust) faulting, Vein systems, penetrative cleavages, melanges. *Fold and thrust belts* — Thrust and fold nappes — *Uplifted volcanic arcs* — extensional faults, fracture patterns associated with intrusions and volcanics. *Fore-arc basins* — local extensional tectonics.	Major overthrust sheets, (allochthonous). Major fold nappes. Major strike-slip faults. *In internal zones* — Fold nappes, contractional (thrust) faults, polyphase deformation. Major strike-slip faults, uplift and late extensional (normal) faults. *In external zones* — Foreland fold and thrust belts, Minor strike-slip faults (generally simpler geometry than internal zones). Development of foreland basins which may become involved in the thrusting.

Table 1.1 (cont'd) Structures associated with particular tectonic regimes.

	ACTIVE PLATE MARGIN REGIMES (Cont'd)			
	Constructive	**Conservative**	**Destructive**	**Collision**
Metamorphism	Range of Metamorphism from Zeolite, Greenschist, Amphibolite. Hydrothermal alteration and vein systems.	Low-grade—sub greenschist burial metamorphism. Local dynamic metamorphism (cataclasites mylonites) and hydrothermal alteration along major fault zones.	High pressure low temperature metamorphism in subduction complexes. Low pressure high temperature metamorphism in interior of arc (associated with intrusions).	*Internal zones*—high-grade polymetamorphism and igneous intrusions, penetrative foliations. *External zones*—Low-grade or burial metamorphism, one or no penetrative foliation.
Examples	Icelandic Rift System	San Andreas Fault System, Dead Sea Transform System	Japanese Island Arc Systems	Himalayan Collision Zone

1.4 Bedding

In sedimentary and many metamorphic rocks, *bedding surfaces* (surfaces of primary accumulation) are our *principal reference frame* (or datum). There are many possible bedforms in sedimentary sequences (see Tucker, 1982 for details) and the structural geologist must be aware that significant departures from layer-parallel stratigraphy can occur in certain sedimentary environments, e.g. deltas; thus structural data must always be collected in conjunction with sedimentological and stratigraphic data.

Bedding is one of the most important structural elements and the structural data that should be collected for bedding are outlined in Table 1.2. *The spatial distribution of bedding or compositional banding (e.g. in gneissic terranes), will define the major fold and fault structures within your mapping area.*

1.4.1 *Way-up/younging and facing*

Way-up/younging is the direction in which stratigraphically younger beds/units are found. (The term *tops* is also sometimes used in this context.)

The *stratigraphic way-up* is of fundamental importance in determining the structure of an area. It is based upon a knowledge of stratigraphy and of small-scale sedimentary structures which indicate the stratigraphic way-up and the sequence of deposition. Sedimentary structures which indicate way-up are discussed in Tucker, 1982 and are summarised in Fig. 1.1. Always look for and record way-up features when mapping.

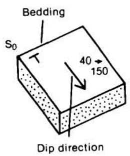
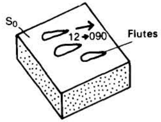
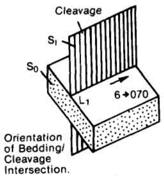
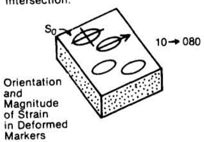
The *structural way-up* refers to the bedding/cleavage relationships that indicate the position within a major fold structure (e.g. on the overturned limb of a recumbent fold). This may have no relationship to stratigraphic way-up. Take care to distinguish the two—see Chapter 3 for greater detail.

Facing is the direction within a structure i.e. along the fold axial plane or cleavage plane, in which younger beds/units are found. This term is generally applied to folds, or cleavage relationships.

1.5 'Synsedimentary' versus tectonic structures

In many areas of deformed sedimentary rocks it is difficult to distinguish between structures formed during deposition or early diagenesis when the sediment was unconsolidated, and those formed after lithification in response to tectonic forces. On cursory examination many 'synsedimentary' structures such as slump folds have superficial geometric similarities to 'tectonic' folds (Fig. 1.2a). Syndepositional faults are also common (Fig. 1.2b) and in some instances syndepositional cleavage fabrics have been observed (Fig. 1.2c). It is therefore extremely important when mapping to distinguish between syndepositional (prelithification)

Table 1.2 Data to be collected from observations on bedding S_0.

Structure	*What to Measure*	*What Observations to Record*	*Results of Analysis*
Bedding 	Dip direction (or strike and dip) (Figs. 2.5,2.6, 2.7).	Lithology, bedding thicknesses Grain-size. Grain shapes, grain fabrics.	
	Orientation of sedimentary structures (Figs. 2.11–2.13).	Sedimentary structures. Geopetal structures.	Depositional surfaces. Palaeocurrent directions. Palaeoenvironments. Way-up—younging.
	Orientation of tectonic structures on bedding plane (particularly the bedding/cleavage intersection) (Figs. 2.11–2.13)	Tectonic structures (cleavage relationships, lineations on bedding plane). (Fig. 4.3b)	Orientation of tectonic structures relative to bedding. (Figs. 4.3b, 5.1b)
	Orientation and magnitude of strain in deformed objects on the bedding plane (Figs. 2.11–2.13 & Appendix III).	Nature of strain relative to bedding. (Fig. 3.12 & Appendix III)	Strain on bedding plane component of layer-parallel shortening. (Fig. 3.12). Relative competencies of units.

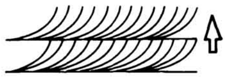
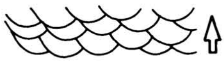
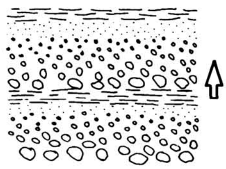
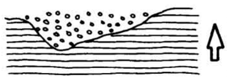
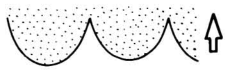
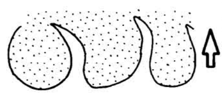
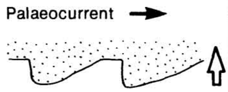
DESCRIPTION	PRIMARY STRUCTURE
CROSS-STRATIFICATION Tabular cross-stratification	
Trough cross-stratification	
NORMAL GRADED BEDDING Coarse grains at the base passing upwards into finer grain sizes; typical of turbidite sequences.	
SCOUR STRUCTURES Scour surface at base of sandstone bed overlying mudrock. Coarse-grained lag deposit may occur in the scour.	
LOAD STRUCTURES Sandstone overlying mudrock Load Casts	
Flame Stuctures Upward injection of mud into the sandstone	
FLUTE CASTS Developed on the underside of Bedding units in Sandstones. Good Palaeocurrent indicators.	Palaeocurrent 

Fig. 1.1 Primary structures that may be used to determine the stratigraphic way-up of beds. (Cont'd on p. 9)