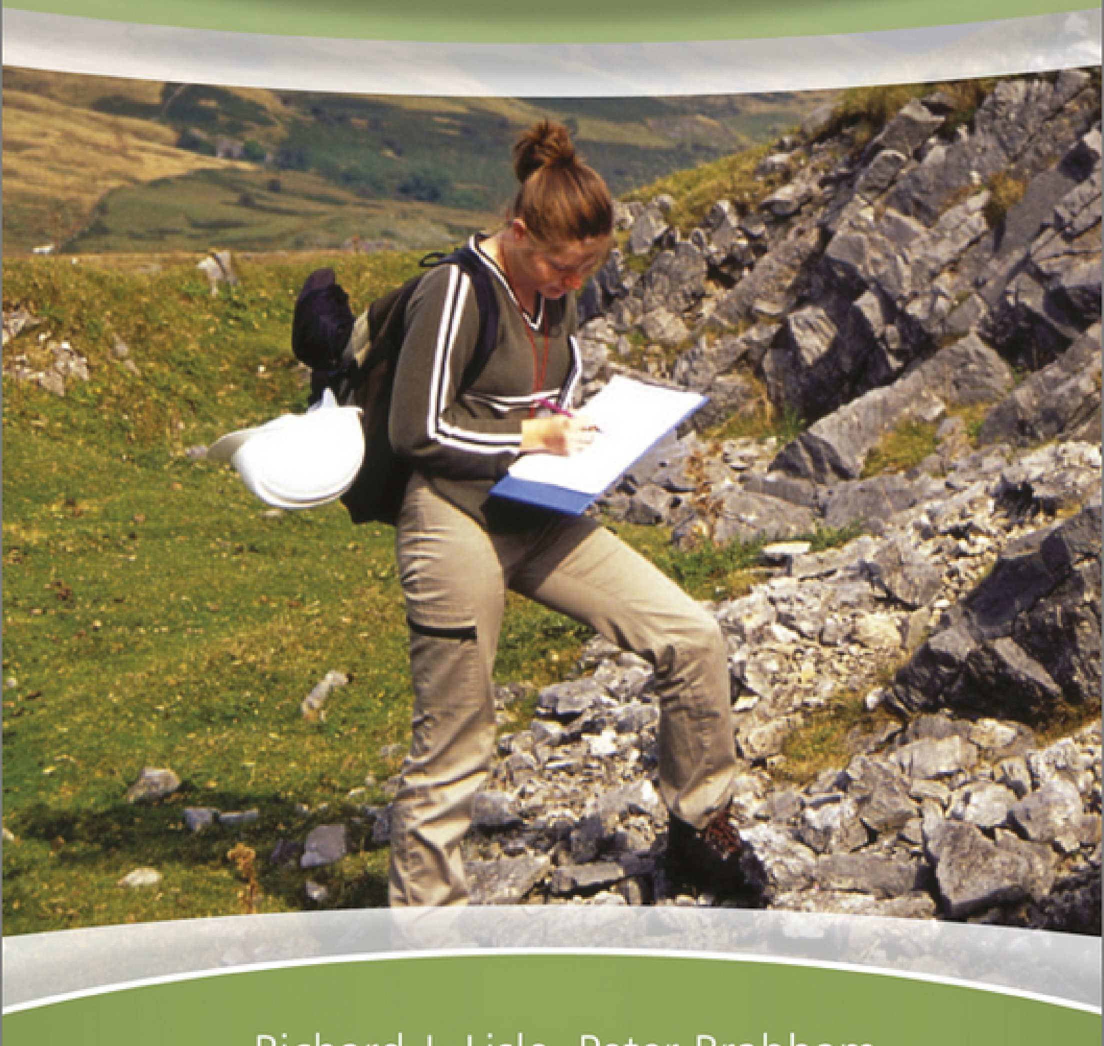
THE GEOLOGICAL FIELD GUIDE SERIES

Basic Geological mapping

FIFTH EDITION



Richard J. Lisle, Peter Brabham and John Barnes

Basic Geological Mapping

The Geological Field Guide Series

The Field Description of Metamorphic Rocks, Norman Fry

The Mapping of Geological Structures, Ken McClay

Field Geophysics, Fourth edition John Milsom

The Field Description of Igneous Rocks, Second edition Dougal Jerram and Nick Petford

Sedimentary Rocks in the Field, Fourth edition Maurice Tucker

Basic Geological Mapping

FIFTH EDITION

Richard J. Lisle
School of Earth and Ocean Sciences, Cardiff University

Peter J. Brabham

School of Earth and Ocean Sciences, Cardiff University

and

John W. Barnes

WILEY-BLACKWELL
A John Wiley & Sons, Ltd., Publication

Wiley-Blackwell is an imprint of John Wiley & Sons, formed by the merger of Wiley's global Scientific, Technical and Medical business with Blackwell Publishing.

Registered office: John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Offices: 9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

111 River Street, Hoboken, NJ 07030-5774, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell.

Library of Congress Cataloging-in-Publication Data

Lisle, Richard J.
Basic geological mapping. – 5th ed. / Richard J. Lisle, Peter J. Brabham, and John W. Barnes.
p. cm.
Rev. ed. of: Basic geological mapping / John W. Barnes, with Richard J. Lisle. 4th ed.
Includes index.
ISBN 978-0-470-68634-8 (pbk.)
1. Geological mapping. I. Brabham, Peter. II. Barnes, J. W. (John Wykeham), 1921- III. Barnes, J. W. (John Wykeham), 1921- Basic geological mapping. IV. Title.
QE36.B33 2011
550.22′3–dc23

2011022844

ISBN: 978-0-470-68634-8

A catalogue record for this book is available from the British Library.

This book is published in the following electronic format: ePDF 978-1-119-97402-4; ePub 978-1-119-97751-3; MOBI 978-1-119-97752-0

Typeset in 8.5/10.5pt Times by Laserwords Private Limited, Chennai, India.

First Impression 2011

CONTENTS

PREFACE TO THE FOURTH EDITION

This book is a basic guide to field techniques used in geological mapping. It is meant to be kept in camp with you and even carried in your rucksack in the field. In addition, because no piece of geological mapping can be considered complete until the geology has been interpreted and explained, chapters are provided on drawing cross-sections, on preparing and presenting 'fair copy' maps, and on presenting geological diagrams from your fieldwork suitable for inclusion in your report. A report explaining the geology is an essential part of any field project, and a brief chapter on the essentials for writing and illustrating it concludes this book. Some emphasis, too, is given to field sketch-mapping because many reports lack those large-scale detailed maps of small areas that can often explain complex aspects of the geology that cannot be shown on the scale of the field map being used, and that are difficult to describe in words. Attention is also given to field notebooks, which are, in many cases, deplorable.

It is assumed that readers of this book have already had at least one year of university or equivalent geology, and have already been told what to look for in the field. Geological mapping cannot, however, be taught in lectures and the laboratory: it must be learnt in the field. Unfortunately, only too often, trainee geologists are left largely to their own devices, to sink or swim, and to learn to map for themselves with a minimum of supervision on 'independent' mapping projects. It is hoped that this book will help in that task.

John W. Barnes and Richard J. Lisle
2003

PREFACE TO THE FIFTH EDITION

This fifth edition of *Basic Geological Mapping* was revised without the help of John Wakeham Barnes who sadly passed away in 2007. On the suggestion of referees we have updated the text by including mention of modern technological aids and data that are used in modern geological mapping, such as applied geophysics, digital terrain models, and optical and GPS-based surveying. There has also been more emphasis given to structural geology and cross-section construction. Whilst making these additions we have been conscious of the need to maintain John's successful formula; to offer a practical guide for the student undertaking a mapping project with a minimum of resources and academic supervision.

We are grateful for the advice of Jim Hendry and Rob Strachan (University of Portsmouth), Chris Berry and Alun Rodgers (Cardiff University) and the book's reviewers.

Richard J. Lisle and Peter J. Brabham
January 2011

1
INTRODUCTION

Most geological maps record the regional distribution of rocks belonging to different formations. However, such maps reveal far more than where we could find rocks belonging to a given formation. The geometrical shape of the different formations on the geological map can also be interpreted in terms of the geological structure and geological history of the region concerned. As an earth scientist you must remember that *accurate* geological maps form the basis of most geological work, even laboratory work. They are used to solve problems in earth resource exploration (minerals and hydrocarbons), civil engineering (roads, dams, tunnels, etc.), environmental geoscience (pollution, landfill) and hazards (landslides, earthquakes, etc.). Making a geological map is therefore a fundamental skill for any professional geologist. As Wallace (1975) states, 'There is no substitute for the geological map and section – absolutely none. There never was and there never will be. The basic geology still must come first – and if it is wrong, everything that follows will probably be wrong.'

There are many kinds of geological map, from small-scale reconnaissance surveys to large-scale detailed underground maps and engineering site plans, and each is made using different techniques. In this textbook, however, we are concerned only with the rudiments of geological mapping. The intention is to provide basic methods and good field practice on which you can further build, and adapt, to deal with a wide range of types of geological mapping.

1.1 Outline and Approach

This book is arranged in what is hoped is a logical order for those about to go into the field on their first independent mapping project. This first chapter includes the important issue of fieldwork safety and appropriate conduct during fieldwork, which should always be considered before anything else. The equipment you will need for mapping is described in Chapter 2, which is followed by a chapter devoted to the many types of geological map you may have to deal with some time during your professional career. A description follows of the different kinds of topographic base maps that may be available on which to plot your geological observations in the field. Methods to locate yourself on a map are

Basic Geological Mapping, Fifth Edition.
Richard J. Lisle, Peter J. Brabham and John W. Barnes.

also described, and advice is given on what to do if no topopgraphic base maps at all are available.

The following four chapters describe the methods, techniques and strategies used in geological mapping, including a brief description of photogeology – that is, the use of aerial photographs in interpreting geology on the ground. A further chapter is devoted to the use of field maps and those most neglected items, field notebooks.

The last three chapters concern 'office work', some of which may have to be done whilst still at your field camp. They cover methods of drawing cross-sections and the preparation of other diagrams to help your geological interpretation. Advice is also given on preparing a 'fair copy' geological map that shows your interpretation of the data from your field map. However, a geological map is not, as is sometimes supposed, an end in itself. The whole purpose is to explain the geology of the area and your map is only a part of that process: a report is also needed to explain the geological phenomena found in the area and the sequence of geological events. Chapter 11 is a guide on how to present this important part of the geological mapping project.

The approach here is practical: it is basically a 'how to do it' book. It avoids theoretical considerations. It is a guide to what to do in the field to collect the evidence from which conclusions can be drawn. What those conclusions are is up to you, but bear in mind what the eminent geologist Lord Oxburgh has said about mapping – that making a geological map is one of the most intellectually challenging tasks in academia (Dixon, 1999).

1.2 Safety

DO NOT PROCEED UNTIL YOU HAVE READ THIS SECTION!

Geological fieldwork is not without its hazards. In Britain, field safety is covered by the Health and Safety at Work Act 1974, and its subsequent amendments. Both employers and workers have obligations under the Act and they extend equally to teachers and students.

The safety risks depend on the nature of the fieldwork as well as on the remoteness, weather conditions and topography of the area being mapped. Before starting the mapping project, a formal *risk assessment* should be carried out. This will determine the safety precautions and the equipment to be carried whilst in the field. Table 1.1 lists some common risks, but your risk assessment must also consider the specific dangers associated with the area to be mapped. This will involve doing your homework before leaving for the mapping, for example consulting topographic maps, finding the address of nearest medical services, looking at tide tables, and so on.

Table 1.1 Common safety hazards associated with geological mapping.

Risk	Precautions
Fall from steep slopes	Stay away from cliffs, steep slopes, quarry edges, overgrown boulder fields, and so on. Do not rely on Global Positioning System (GPS) but examine a topographic map to identify steep slopes and plan your route. Avoid climbing; leave dangerous exposures unmapped rather than take risks. Do not run down slopes. In mountains but not on a path, stay put in dense mist, fog and darkness
Struck by falling rock and splinters from hammering	Avoid rock overhangs; wear a helmet if near cliffs, quarry faces. Do not enter mines or caves. When hammering always use safety goggles and take care with bystanders and passers-by
Drowning after being swept away by waves, tides and floods	Avoid the water's edge at sea, lakes and rivers. Consult tide tables. Do not enter caves, mines, potholes. Do not attempt to cross fast-flowing rivers
Cannot be reached by emergency services	Work in pairs, or in close association; leave details of the day's route in camp before leaving for the field; wear bright clothing, carry a mobile phone, whistle, torch, flashing LED beacon or a mirror to attract the attention of passers-by or mountain rescue teams
Exposure, an extreme chilling arising from sudden drop in temperature	The symptoms range from uncontrolled shivering, low body temperature, exhaustion and confusion. Carry warm clothing and waterproofs, thermal safety blanket, matches, emergency rations (e.g. glucose tablets, water)
Motoring accident	Drive carefully on narrow mountain roads; at roadside exposures take care with passing traffic and wear high-visibility jackets. Never drive whilst under the influence of alcohol or drugs.

A geologist should be able to swim, even if fully clothed. If you swim you are less likely to panic when you slip off an outcrop into a river; or from weed-covered rocks into the sea or a rock pool, or even if you just fall flat on your face when crossing a seemingly shallow stream. Such accidents happen to most of us sometime. If you are faced by something risky, play it safe, especially if you are on your own. A simple stumble and a broken ankle in a remote area can suddenly become very serious if nobody knows where you are and you are out of mobile phone coverage.

In some northern latitudes (e.g. northern Canada, Svalbard) geologists have to carry guns and flares to ward off the unwanted attentions of polar bears. So if you are planning work abroad, do your homework on special dangers before you go.

1.3 Field Behaviour

Geologists spend much of their time in the open air and, more often than not, their work takes them to the less inhabited parts of a country. If they did not like being in open country, presumably they would not have become geologists in the first place: consequently, it is taken for granted that geologists are conservation-minded and have a sympathetic regard for the countryside and those who live in it. Therefore, remember the following:

1. Do not leave gates open, climb wire fences or drystone walls or trample crops, and do not leave litter or disturb communities of plants and animals.
2. Do not hammer for the sake of it. Greenly and Williams (1930, p. 289) observe that 'indiscriminate hammering is the mark of a beginner' (several key localities once showing beautiful structures have been defaced by geological hammering, drilling and graffiti). When you are collecting specimens do not strip out or spoil sites where type fossils or rare minerals occur. Take only what you need for your further research.
3. Before you embark on any field programme you should have studied your public access rights on footpaths using maps or web-based enquiry. In the UK, you do not have the right to walk wherever you want, but open access to many remote areas is now covered by the Countryside and Rights of Way Act 2000. These are typically areas of mountain, moor, heathland, downland and registered common land; further details can be found on the Ramblers website. When in the field always ask permission to enter any private land when not on a public footpath. Most owners are willing to cooperate with geology students if they are asked politely first; landowners are usually very interested in what lies beneath their land, but understandably get very annoyed to find strangers sampling their rocks uninvited.

If working in a foreign country, carry a simple A5 size laminated card explaining in the local language who you are and what you are doing; this often diffuses any conflict and confusion with landowners due to your poor communication skills. Bear in mind that irate farmers can inhibit/restrict geological activities in an area for years to come, and this has already happened in parts of Britain. Many other countries are less populated and have open space, and the situation may be easier, but every country has some land where owners expect you to consult them before working there. If in doubt, ask! (See also the *Geological Fieldwork Code* published by the Geologists' Association, 2000.)

1.4 A Few Words of Comfort

Finally, some cheering words for those about to start their first piece of independent mapping. The first week or so of nearly every geological mapping project can be depressing, especially when you are on your own in a remote area. No matter how many hours are spent in the field each day, little seems to show on the map except unconnected fragments of information that have no semblance to an embryonic geological map. Do not lose heart: this is quite normal. Like solving a jigsaw, the first stages are always slow until a pattern starts to emerge; then the rate of progress increases as the separate pieces of information start fitting together.

The last few days of fieldwork are often frustrating for, no matter what you do, there always seems to be something left to be filled in. When this happens, check that you do have all the essential information and then work to a specific finishing date. Otherwise you will never finish your map.

Detailed fieldwork preplanning, executing a daily field plan and good time management are often the keys to success.

2

FIELD EQUIPMENT

Geologists need a number of items for the field. A hammer (sometimes two) is essential and some chisels. Also essential are a compass, clinometer, pocket steel tape and a hand lens, plus a map case, notebooks, map scales, protractor, pencils and eraser, an acid bottle and a penknife. A camera is a must, and a small pair of binoculars can be useful at times, for studying dangerous or inaccessible cliffs from a distance.

A GPS is very useful for field mapping, but it must never be totally relied upon as your only way of determining where you are. Remember GPS units do not work if their batteries run down or if there is minimal sky cover, that is in forests, quarries, and so on (see Section 3.5.10).

A 30 m tape will sometimes be needed and a stereographic net. If using aerial photographs you may need a pocket stereoscope or a pair of stereo glasses. You will also need a felt-tipped marker pen for labelling specimens. Make sure it writes on plastic and is totally waterproof. Finally, you will need a rucksack to carry it all, plus a water bottle, emergency rations, a first-aid kit, whistle, perhaps an extra sweater, your mobile phone and, of course, your lunch.

Geologists must also wear appropriate clothing and footwear for the field if they are to work efficiently, often in wet cold weather when other (perhaps more sensible) people stay indoors; inadequate clothing can put a geologist at risk of hypothermia (see Section 1.2). A checklist of what you may have to pack before a field trip is given in Appendix B, but this is an exhaustive list to cover various types of geological fieldwork in various climates; refer to it before setting out to your field area base.

2.1 Hammers and Chisels

Any geologist going into the field needs at least one hammer with which to break rock. Generally, a hammer weighing less than about 0.75 kg (1.5 lb) is of little use except for very soft rocks; 1 kg (2–2.5 lb) is probably the most useful weight. The commonest pattern still used in Europe has one square-faced end and one chisel end. Many geologists now prefer a ‘prospecting pick’; it has a long pick-like end that can be inserted into cracks for levering out loose rock, and can also be used for digging though a thin soil cover. Hammers can be

Basic Geological Mapping, Fifth Edition.
Richard J. Lisle, Peter J. Brabham and John W. Barnes.

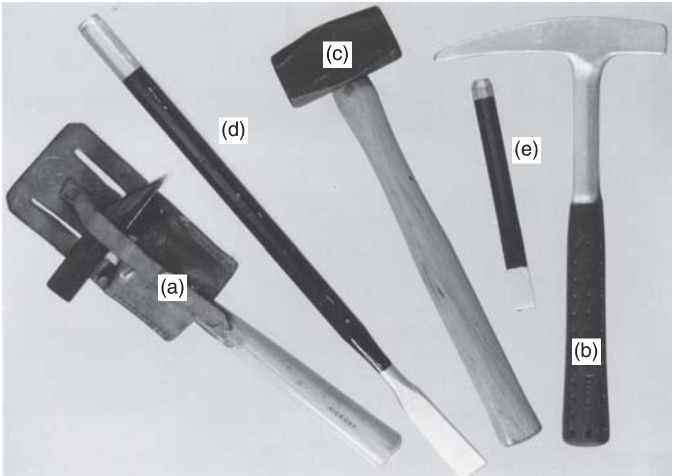


Figure 2.1 *Tools for the field. (a) Traditional geologist's hammer in leather belt 'frog'; (b) steel-shafted 'prospecting pick'. (c) Bricklayer's 'club' hammer with a replaced longer shaft. (d) A 45 cm chisel with 2.5 cm cutting edge and (e) An 18 cm chisel with 2 cm edge. (After Cooper, G.R. and C.D. McGillem, 1967:* Methods of Signal and System Analysis. *Holt, Rinehart and Winston, New York, 432 pp.)*

bought with either wood or fibreglass handles, or with a steel shaft encased in a rubber grip (Figure 2.1).

Geologists mapping hard igneous and metamorphic rocks may opt for heavier hammers. Although 2 kg (4 lb) geological hammers are available, a bricklayers 'club' hammer, with a head shaped like a small sledgehammer, can be bought more cheaply; but replace its rather short handle by a longer one bought from a hardware store.

Hammering alone is not always the best way to collect rock or fossil specimens. Sometimes a cold chisel is needed to break out a specific piece of rock or fossil. The size of chisel depends on the work to be done. Use a 5 mm (1/4 inch) chisel to delicately chip a small fossil tree from shales; but to break out large pieces of harder rock a 20–25 mm (3/4 inch) chisel is required (Figure 2.1). One thing you must never do is to use one hammer as a chisel and hit it with another. The tempering of a hammer face is quite different from that of a chisel head, and small steel fragments may fly off the hammer face with unpleasant results. Eye damage due to rock or metal splinters is often permanent, so again always wear safety goggles when hammering.

Some geologists carry their hammers in a ‘frog’, or holster, as this leaves their hands free for climbing, writing and plotting. They can be bought or easily made from heavy leather (Figure 2.1). Climbing shops stock them for piton hammers although some may be too small to take a geological hammer.

2.2 Compasses and Clinometers

The perfect geologist’s compass has yet to be designed. Americans have their Brunton, the French the Chaix-Universelle, the Swiss have their Meridian, whilst the Germans have their Breithaupt Clar compass. All are expensive. Many geologists now use the very much cheaper mirror compasses: the Swedish Silva 15TD/CL, the Swiss Recta DS50 or the similar Finnish Suunto MC2 (Figure 2.2a). All of the above have built-in clinometers. The Silva and Suunto compasses (Figures 2.2 and 2.3), however, have a transparent base so that bearings can be plotted directly onto a map by using the compass itself as a protractor (see Figure 3.4). However, prismatic compasses, which have a graduated card to carry the magnetic needle, are perhaps easier for taking bearings on distant points. All these compasses except the Brunton are liquid-filled to damp the movement of the needle when taking a reading. The

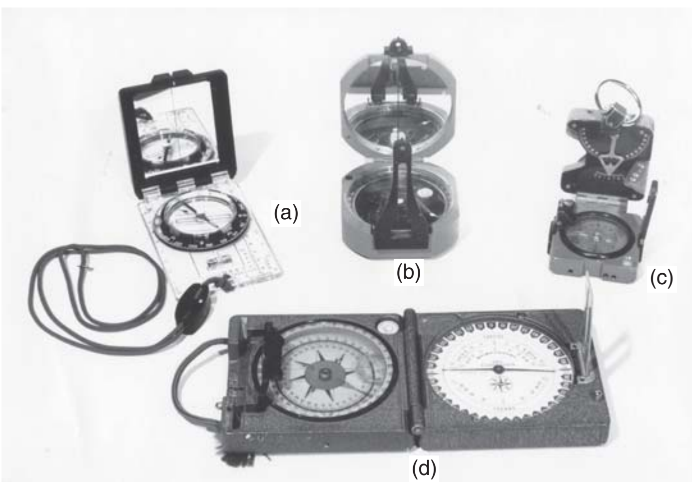


Figure 2.2 *Compasses designed for the geologist. (a) Finnish Suunto compass, similar to the Swedish Silva Ranger 15 TDCL. (b) American Brunton ‘pocket transit’. (c) Swiss Meridian compass and (d) French Chaix-Universelle. The Brunton and Meridian can also be used as hand levels.*

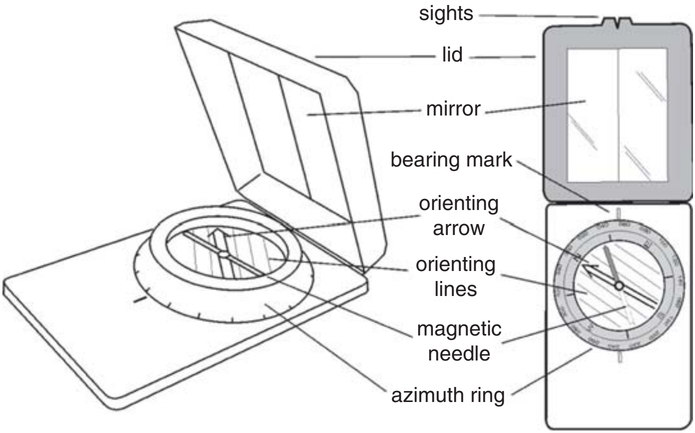


Figure 2.3 *The mirror compass. (After Cooper, G.R. and C.D. McGillem, 1967:* Methods of Signal and System Analysis. *Holt, Rinehart and Winston, New York, 432 pp.)*

Brunton is induction-damped. Some compasses can be adjusted for work in variable latitudes (Recta, Silva).

2.2.1 Compass graduations

Compasses can be graduated in several ways. The basic choice is between the traditional degrees and continental grads. There are 360° in a full circle, but 400 grads. Both are used in continental Europe and if you do buy a compass in Europe, check it first. If you opt for degrees, you must then choose between graduation in four quadrants of 0–90° each or to read a full circle of 0–360° (azimuth graduation). We recommend using the azimuth, since bearings can be expressed more briefly and with less chance of error and confusion. Comparisons are made in Table 2.1.

Table 2.1 *Equivalent bearings using quadrant and azimuth conventions.*

Quadrant bearing	Azimuth bearing
N36°E	036°
N36°W	324°
S36°E	144°
S36°W	216°

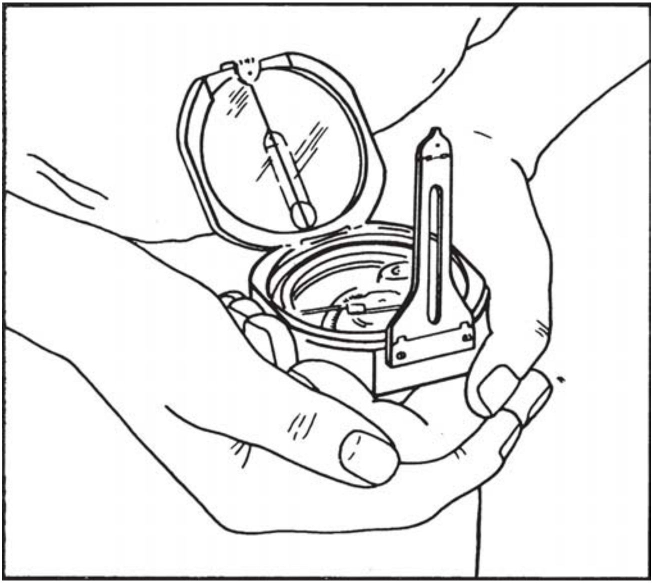


Figure 2.4 *The recommended way to use a Brunton compass when taking a bearing on a distant point.* (Reproduced by courtesy of the Brunton Company, Riverton, Wyoming.)

2.2.2 Using compasses

Prismatic compasses and mirror compasses are used in different ways when sighting on a distant point. A prismatic is held at eye level and aimed like a rifle, lining up the point, the hairline at the front of the compass and the slit just above the prism. The bearing can be read in two ways. The Brunton Company recommends that the compass is held at waist height and the distant point aligned with the front sight so that both are reflected in the mirror and are bisected by the hairline on the mirror (Figure 2.4).

With the Silva-type mirror compass, sight on the distant point by holding the compass at eye level and reflecting the compass needle in the mirror (Figure 2.5). In fact, some prefer to read a Brunton in the same way. Mirror compasses have a distinct advantage over prismatic compasses in poor light such as underground in mines. Specialist mining compasses can be used in the dark by pressing a button to clamp the compass reading, so you can then study the compass needle under the light of a cap lamp.