GEOLOGICAL MAPPING

In this hand-out, the main methods whereby a geologist records his observations of rock structures on a map and in a field note book will be outlined. The techniques employed for mapping vary somewhat from person to person, but there are a number of basic ground rules, and these are formulated here. Field investigations and the production of a map record of field observations form important keys to our understanding of the structure of the Earth. We can see exposed at the surface today a complete range of depths of erosion through the crust and even, at some localities, into the upper mantle. The field geologist is able to build from these observations a complete picture of the type of variation in structural style and the nature of the deformation that has occurred during the tectonic activity of the past.

EQUIPMENT

Topographic base map

Before starting any mapping project it is important to be clear about the aims of the investigation, for this decision will guide the choice of map scale and control the nature of the techniques which are needed to cover the area in the detail necessary to resolve the problem. For exploration work, map scales of 1:100,000 to 1:25,000 are ideal. For more detailed geological work, mapping is normally carried out at scales of 1:25,000 to 1:5,000, and it will be possible to record most of the important geometric features of folds and fractures. For very detailed surface mapping, such as would be appropriate to investigating a mine claim, scales of 1:1,000 to 1:50 may be the most convenient, and these often require the geologist to make his own topographic base. In many regions no suitable topographic base maps that are of sufficient accuracy exist and the geologist will have to rely on **air photographs or satellite images**. Even where a good topographic base is available, air photographs or satellite images are especially useful in aiding a geological interpretation of an area. In the field it is possible to make geological observations in ink directly on a transparent overlay. However, air photographs are not maps because they are often slightly tilted with respect to the vertical and, in hilly or mountainous terrain, the photographic image is falsely located because of parallax. This positional error increases from the center towards the edge of each photograph. In some countries air photographs are compiled into **photographic mosaics**. These can be controlled or uncontrolled depending upon whether or not the centers of each photograph making up the mosaic are correctly related in scale and position. It is quite easy to make an uncontrolled mosaic oneself, but the production involves cutting away the edges of each photograph and pasting the prints on to a hard base board. If a second set of air photographs is not available to make a mosaic, it is sometimes useful to make a loosely controlled **print lay-down** of the existing photographs and to prepare a photographic version of this assemblage. In all mosaics and print lay-downs the detail between adjacent photographs will not line up because of variations of surface topography, air photo tilt and airplane flying height. The availability of maps and air photographs is, in certain countries, restricted for military or political reasons. Remember, however, that Landsat images over a wide range of color and infra red bands can be obtained of all of the Earth's surface, and that various high quality processing and enlarging techniques can transform these images into a practical working topographic base suitable for many types of regional geological investigation.

The topographic base map will generally be too large for direct work in the field. It should *never* be folded because information recorded near the folds will be subjected to excessive wear and tear during use, and eventually will disappear. It is best to cut the base map into sheets of a size that is conveniently contained in your map case. Do not make these sheets too small or you will always be frustrated by finding yourself near an edge or, worse still, near a corner, and you will constantly have to shuffle your map sheets like a card player. The size 20 x 30 cm is ideal. Each of the cut map sheets should be mounted onto a base card, leaving a small margin around the map to protect its edges from wear. On the corner of each card number the sheets sequentially (A1.A2.A3,...,B1,B2,B3,..., etc.) so that you can quickly locate the next sheet as you move across the area. Indicate in ink the reference numbers of an existing (or personal) grid system so that you can refer exactly to individual map localities in your field note book. You will need some hard base (or map case) in order to be able to write effectively on your field map, together with some protection of the map from rain, dust or sweaty hands. Map cases can be highly sophisticated constructions with flaps, pockets for note books, air photographs, etc. and holders for pencils. The minimum requirements are a base of hard board, plastic or aluminium with a strong spring clip at one end to attach the map and a moveable elastic band at the other end to stop the map lifting in the wind, together with a plastic sheet for a cover. Field techniques generally require constant use of a number of black graphite and colored pencils, and it is useful to have pencil holders on the map case or incorporated in a shoulder bag (where you can also have space for a note book, eraser and pencil sharpener and any other constantly used field equipment).

Pencils

Black pencils are used to record orientation data, and colored pencils are used to record rock lithology on the field map. Colored pencils should be of a waterproof type and should have a relatively thin colored lead which has a strong consistency. You will have to acknowledge that pencils will get lost during the course of your work. Thus, you will need at least one spare set of colored pencils at the base camp, and you will definitely need to carry spare black pencils with you in the field.

Never record any field information directly onto the map in ink. Everyone makes mistakes at some time and it is very difficult to erase inked data. It is best to record information with a sharp, relatively hard pencil and to ink in this information at the end of every field day. A rule that must be observed without fail is *never* to go into the field with a map that contains data that has not been previously inked.

In using colored pencils for recording lithology always keep your color scheme simple, and the colors well contrasted. Choose a color scheme for the various mapable formations that, wherever possible, conforms to a previously accepted set of standard colors. However, remember that the color schemes that appear on published maps are not always the most practical schemes for the field map: five different shades of green might be perfect on a published map, but such a sophisticated scheme is unrealistic on a working field map subject to everyday wear and tear.

Compass and clinometer

These are absolutely essential instruments for recording azimuths and inclinations. The magnetic compass must be robust and simple to use. There are a great variety of instruments available today and many which are especially convenient for geologists combine a compass and clinometer in one instrument. Geological azimuth data need to be recorded to the nearest degree, so choose a compass with a scale which enables this to be done. It is occasionally necessary to find your location on the topographic base map by resection from distant landmarks, and this means that the compass must have some system of glass prism or mirror sight to be able to observe these landmarks and the compass scale at the same time. Another extremely important feature for a geologist's compass is that the magnetic needle or magnetic plate system should have a damping mechanism (an oil filled compass is best) so that the azimuth point comes quickly to rest.

The magnetic field of the earth can be represented by an array of lines that run from one magnetic pole to the other. At a given locality on the earth, the moving element of the compass, the magnetized needle, aligns itself with the magnetic field line at that locality. The needle is usually balanced so that it lies parallel to the horizontal plane at the point of measurement and therefore gives the horizontal component of the magnetic field. Averaged over long periods of time, the magnetic dipole of the earth corresponds to the spin axis of the earth, so that the magnetic poles are the same as the *geographic poles* (the geographic poles are the points at which the spin axis pierces the earth). At any given time, however, the magnetic poles may be located at a distance from the true poles. Today, for example, the north magnetic pole is located in northern Canada. The acute angle between the direction of true north (a line of longitude) and the direction that the compass needle points in the present-day magnetic field is called *magnetic declination*. A declination of 12° east means that the angle between true north and magnetic north is 12°, and that true north lies 12° counterclockwise from magnetic north. Values for magnetic declination at a given time in the United States can be plotted on a map. The magnetic pole drifts slightly every year, so such maps must be constantly updated.

As we noted earlier, the reference frame used to specify locations and orientations on the earth's surface is keyed to the geographic poles. Therefore, a correction must be made in order to account for magnetic declination. By making this correction, the compass pointer is pointing to true north when the white end of the needle is lying on 0°, even if the needle is not parallel to the pointer. A Brunton compass may be set for the magnetic declination of a map area by turning the screw on the side of the compass; this screw rotates the compass card with respect to the pointer. Figure 1 shows compasses set for two different magnetic declinations.

A compass is such a key field instrument that its loss during field work could lead to disaster. Keep your compass firmly attached either to your map case, field bag or your person with a strong nylon cord. If you plan to work in a very remote region, you should take a spare compass to be kept in the base camp for emergencies.

A clinometer is most conveniently incorporated into the compass, and many equipment models do this. Like azimuth directions, the angle of inclination must be measured to the nearest degree.

Field notebook

Information that cannot be recorded on the geological map is written in the notebook. The most convenient size for such a book is about 20 x 10cm, it must be strongly bound and made of good quality paper. It is a personal choice whether the pages are unlined, lined or with a grid system. You will constantly be needing to find your next entry point in the book -- some notebooks have a tape marker embedded in the binding. If your notebook does not have this, organize an elastic band to provide a moving book mark. A lost field book is a geological tragedy, and a brightly colored notebook binding will reduce the risk of casual loss. In any case, always write your name, address and telephone number on the first page. It might be useful to include that postage will be repaid to the finder of your notebook.

Whether field notes are recorded in pencil or ink is a matter of personal choice. Soft pencil produces a strong black line without problems of interpage smearing. Personally, I do not favor direct recording of written or diagram data in ink. However, many geologists today use barrel and wire pens and record their field notes directly in ink. Although these pens are excellent for ink work in the base camp, there are a number of practical disadvantages in the field. Pens with a fine diameter (<0.3mm) often dry out and become blocked in the field, and all of these pens are extremely susceptible to changes in temperature and pressure and often extrude ink in a totally uncontrollable manner with atmospheric changes.

Hammer and soft steel chisel

A hammer is a critical tool for obtaining rock specimens for laboratory work and for chipping away weathered rock surfaces. In many classic localities the outcrops have been literally pulverized by the activity of geologists. There is a code of hammer activity: never destroy interesting structures by uncontrolled hammering and never remove fossils from a natural outcrop unless there is a good scientific reason for doing so. Remember that, for most purposes, the information about rock types can just as well be obtained by observations on naturally fallen blocks. If you wish to obtain a particular block of rock from an outcrop, it is best to use a soft steel rock chisel with the hammer. Never strike one hammer against another because hard steel shards are likely to break from one of the hammers and fly around like shrapnel.

Although a geologist should never lose his hammer, let us admit that many of us do. A good practical tip for lessening your chance of leaving your hammer at an outcrop is to paint the handle of your hammer some strikingly bright color (e.g. orange) so that it can be easily distinguished from the color of the local rock and vegetation.

Hand lens

A good hand lens with a moderate magnification (x10) is absolutely essential for the examination of a fresh rock surface to determine such features as mineral content, grain shape and micro fossils in a rock. Tie your hand lens to your field bag with a piece of strong nylon cord or, even better, wear it around your neck where it is ideally positioned to make frequent observations.

Drafting materials

Only the simple equipment that is necessary for base camp work after a day in the field are discussed here. A firm board for providing a stable base for "inking-in" the maps is essential. Inks are essential for making the pencil record made during the day permanent. The ink should be waterproof. You will need a soft eraser to remove the pencil lines and, because everyone makes errors, a razor blade and hard ink eraser. The type of pen used is a matter of personal taste; barrel pens (Rotring, Rapidograph, Faber-Castell, Staedler, Kern) are excellent. A protractor and ruler will often be required at some stage in the redrafting, and a stereogram or equal area projection will be required to analyse orientation data.

Other equipment

Most geologists carry extra items of equipment in addition to those listed above, depending on their personal approach to field work and upon the special nature of the problem in hand. A measuring tape is useful if very detailed mapping is to be undertaken so that features such as bed thickness, joint spacing, etc., can be accurately recorded. A bottle of 10% concentration **hydrochloric acid** is most useful in areas where calcite needs to be distinguished from dolomite. More elaborate chemicals can be carried where the geological problem in hand demands these. A small field **stereogram or equal area projection** can be used to make geometrical computations directly in the field. Although most interpretation of air photographs will be done in the base camp some geologists like to carry a **folding pocket stereoscope** to be able to make these observations in the field. If a good topographic base map with well-controlled contours is available, an **altimeter** is a great assistance to position location in the field. In the mountains, where certain exposures may be inaccessible, **binocular field glasses** are a great aid to observe structural detail. Finally, do not forget to bring a raincoat and, especially, lunch!

GEOLOGICAL MAPPING PROCEDURES

The aims of the investigation and the amount of time available for field work will dictate the data collection. In regional exploration mapping is it important to plan so that the distribution of available field time will enable a complete cover of the whole area. This will mean that you will generally have to rely on traverse mapping, and you should plan these traverses so that they cross the strike of the different rock units. With a more detailed mapping project, such as those at field camp, it is possible to visit practically all the rock exposures. Whatever problem faces the geologist three basic constraints are applicable to every type of field mapping:

1. *The field map must be legible.* This means that it is essential to use the right type of equipment and that you must be accurate and neat. The field map must be a permanent record of your observations in ink.
2. *The field map must be readable by another geologist.* This requires that the observations must be plotted using consistent standard symbols (see Appendix) rather than haphazard personal hieroglyphics and that, somewhere in the collection of field sheets, there must be a key to the symbols used and a legend to the color code used to represent the different rock types.
3. *A field map must distinguish between observed facts and inferences drawn from these facts.* It is therefore necessary to indicate the differences between exposed and unexposed terrain, between observed and inferred contacts of different rock units. The limits of actual rock exposures need to be indicated on the map and a practical map technique to show exposed and inferred rock types is to color outcrops with a strong color, and regions where the same rocks are believed to exist in a weak color of the same hue (Figure 1).

At the start of the field investigation it is usually a good idea to make a preliminary traverse through the area to obtain a general impression of the nature of the geological problem, to decide on the main lithological subdivisions you might record on the map, and to decide on the types of small-scale structural features that require mapping. It is sometimes a good idea to spend a little time looking at the boulders in streams because these can give a useful first

impression of the rock types likely to be encountered in the catchment area of that particular stream. It is best to commence mapping where the least weathered, best exposed and most accessible exposures are located.

Having arrived at a rock outcrop the first thing to do is to find your position on the map, either from simply identifiable features recorded on the topographic base or aerial photograph, or by resection of distant features using the compass to ray-in your position (two or three features are required for this). Mark the locality on the map and note the lithological type and any general and special features of the rock (mineral composition, grain size, weathering) in your field book. If the rock is of sedimentary origin, look for diagnostic sedimentary structures and, if possible, determine their geometry so that it will be possible to reconstruct the directions of transport of the sediment depositing current (cross bedding, ripple marks, bottom structures in turbidites). If the area is tectonically complex, these primary sedimentation features can be used to determine the younging direction of the beds (normal or overturned strata). In sedimentary rocks search for fossils which might give an indication of rock age (zone fossils) or indicate the conditions of deposition (paleoecology). Search for tectonically produced structures (cleavage, folds, lineations, joints, etc.) and for deformation markers that might be used to establish the principal strain directions and values. Note all these features in the field book and sketch particularly important geometric relationships. You may decide that the outcrop shows certain features so well that it should be placed on photographic record. Remember to include a scale in the photograph, to note the exposure number and to make a quick sketch in the notebook of the field of view, recording rocks types and nature of any structures. However, do not rely on a photographic record alone. When making a photo, always remember to get as close to the outcrop as possible while keeping the subject material in the field of view. So many photographs are disappointing because the object of importance is subsidiary to a mass of vegetation or of rocks showing no features in particular. Most modern cameras can focus down to <0.5m, and with lens rings or a macro lens unit it is quite possible to take photographs at distances of a few centimeters from the object. Remember that greater range of depth of focus occurs where the *f*-number requires a longer time of exposure, which may give movement problems if the camera is held in the hand. Before you take a photograph remember to clean up the outcrop surface by removing stones, leaves and distracting vegetation. In the field one may not notice the effect of a blade of grass or its shadow, but when the film is printed these geologically insignificant things may often detract from the features that are of geological importance.

The field map

On the map indicate in pencil the limits of the actual outcrop as accurately as possible and then, also in pencil, lightly color the mapped outcrop according to your lithological color scheme. Measure any **planar structure** (bedding, cleavage, banding, jointing, etc.) first recording the *strike* with a compass to the nearest degree and second the *angle of dip* and its *directional sense*; e.g., 143/76 SW. Make sure that the magnetic azimuth reading is corrected to true north. You record this information in your field book, but you should also *record the most important geological readings directly on the map in the field*. With a protractor *accurately* draw the strike line and indicate with a side tick the dip direction. These data are recorded on the map in symbol form (see Appendix), and the dip measurement made should be written next to the symbol. Two methods of recording the numerical data in your note book are in common use. The first records the strike direction together with the angle and approximate direction sense of the dip, e.g., 143/76 SW. The second method describes the *direction* of the dip using a 360° compass notation followed by the angle of dip, e.g., 233/76. With the second method the direction sense is not necessary because it duplicates the information of the dip tick symbol, but it does give a useful check to avoid mistakes. To avoid confusion, it is wise always to use three numbers for the strike or dip direction, and two for the dip; e.g., 007/04. Which of the measurements of planar structures you record directly on the map will depend upon the nature of the geological problem you are trying to solve but, in principle, record as many features as possible. Geological mapping is often a very stimulating exercise just because the geological significance of individual outcrops gradually emerges during the course of the work, just like a jig-saw puzzle picture is gradually revealed as the separate pieces are assembled. A criticism that can be made of many field maps is that they do not contain enough measurements and records of structural information. A novice will clearly take quite some time to identify, measure and record a particular structure, but an experienced field geologist can be expected to make between 50 and 200 measurements each day. Such a large data base is absolutely invaluable in providing a firm base for a geologic interpretation. Another important aspect of measuring orientations of structures is that it forces the geologist to observe carefully and identify features which, with a more casual investigation, might be overlooked. The second type of basic orientation information relates to the orientation of **linear structures** (fold axes, intersection lines of cleavage and bedding surfaces, stretching directions in deformed rocks, striae on fault planes, etc.). The **trend or azimuth** of the lineation is measured with the compass and the angle of inclination from the horizontal, i.e. the **angle of plunge**, with the clinometer. These data should be accurately recorded in pencil on the map in the field using an arrow symbol and in your note book; e.g., 252/26. Remember that a linear structure plunging towards the WSW has a different arrow sense from that plunging ENE, and that the plunge should be recorded by the symbol. All primary and secondary structures can be classifed either as planar or linear features, and it is normal to denote different types of these features using variations in the basic notation or in color of the symbols. Some geologists use color coded symbols when they make a permanent record of their data in ink at the end of the day; black for basic features (bedding, polarity sense) and red for tectonic features (cleavage, fold axes). There are no unique symbols for the various types of features you will record, but a list of suggestions is given in the Appendix. Whatever you use from this list, make a record somewhere on the field sheets of your notation.

The field map will develop day by day as information accumulates. Comparing the maps of different geologists, one sees a wide range of different techniques and approaches, some of which are to be discouraged whereas others can be recommended in helping to provide useful and high quality data collection. Beginners often produce a map which is just a series of locality numbers. All the data are placed in the field book and little or none on the map. Such a record is practically useless, and the geologist who uses such a technique is unlikely to see many of the major geological and structural problems of the region. These will only emerge when the data are plotted back at the office, and one may find it necessary to return to the area or leave the problem in an unsatisfactory and unresolved state. Furthermore, with this technique it is most unlikely that, during the data collection in the field, the geologist's mind has been actively working and thinking about the outcrop relationships from locality to locality. Many of those geologists making such a data record find field work boring and regard the activity as only necessary for supplying themselves with a series of hand specimens for later work in the laboratory.

Another technique which can be criticized is the production of a solid geological map of the bedrock formations directly in the field. With this technique it is not always clear what evidence there is behind the construction of geological boundary lines, what is reasonable inference and what is just guesswork. It is best to clearly demarcate the observations and the inferences made from them (Figure 2). The differences between exposed and inferred boundaries are clear, and so are the differences of degree of certainty between different types of inference. Any geologist who later has to use such a map will know exactly where to find the exposures and where to seek additional information should that be necessary. With this technique *do* make interpretations in the field. For example it is often relatively easy to see where unexposed boundaries might be located during the course of the field work, especially if the topography is varied and complex. On such a field map it will be possible to record many features which may provide excellent indicators of sub-soil geology: slope changes, springs, soil color, vegetation changes, etc. Without interfering with the solid geology record it is also possible to indicate information about Quaternary deposits (moraine, alluvium, rock falls, etc.) using a variety of different point, circle and triangle symbols. After a day in the field it is often an excellent idea to make a full-colored pencil interpretation of the subsurface geology using weaker color intensities than those of exposed outcrops.

Sample collection and record

During the course of a field investigation you may need to collect samples of rocks for later investigations of features in the laboratory. In the field you will need to mark each rock specimen clearly with a sequential number using a waterproof felt tip marker pen and to record with grid coordinates the rock type and location in the note book. The sample number can also be recorded on the map. One convenient technique is to make a pin prick on the map at the sample locality and to record the specimen number *on the back* of the map sheet. For specimens which show important structural characteristics the collected sample should have an orientation mark so that any information resulting from further laboratory study can be directly related to the field. It is recommended that all samples are oriented in this way. To collect an oriented sample a surface of the outcrop is selected which preferably shows some clearly marked planar surface. Often this surface will have some structural significance, e.g., a bedding, cleavage or joint plane. The sample is then broken from the outcrop and then placed back on to its parent, perhaps with the assistance of sticky tape. The strike azimuth and dip orientation of the surface are then measured, and the data recorded in the note book. The strike and dip directions are then marked on the rock sample with a felt tip pen, perhaps together with the orientation numbers, before the specimen is detached from the outcrop. Do not forget to number your samples and record this in your note book. It is convenient to use the same number for the specimen and the outcrop, e.g., 14A or 88-14A.

CONCLUDING REMARKS

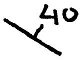
The maps produced by geologists vary from scruffy, torn, illegible pieces of paper to near works of art. You will probably not make ideal field maps when you take your first steps in field mapping. However, with increasing experience and continuous self-criticism of your efforts, even those who are not born with a sense of neatness, or who have little or no inherent drafting ability, can produce good quality geological maps. Aim at the highest standard possible. If you are working in a group making a geological map, compare your efforts critically with those of your colleagues.

Field mapping is an enjoyable and stimulating intellectual activity. Remember, however, that it is not only an academic exercise. For the professional geologist a good accurate mapping technique provides the fundamental data necessary for much research and development. The investment of large sums of money on major civil engineering, mining or petroleum development may partly depend upon the reliability of your field observations and your map. If your data collection and record was poorly made, you will, at best, be unpopular with your project chief and, at worst, you may find yourself looking for new employment.

Appendix: map symbols

Primary structures

A. *Planar*: lithology, layering, banding in gneisses, flow banding and flow layering in igneous rocks.



strike and dip, basic notation


vertical


horizontal

polarity of layering

"normal" layering

"overturned" layering


exposed lithological contact


inferred (certain) lithological contact


inferred (undertain) lithological contact

B. *Linear*: bottom markings in turbidities (flute casts, groove casts, bounce casts, etc.), ripple crests, flow lineations in igneous rocks.

azimuth and angle of plunge

horizontal

vertical

Secondary structures

A. *Planar*: fold axial surfaces, cleavage, schistosity, fracture planes, shear zones, joints.

strike and dip, basic notation

suggested variations on basic symbol


vertical


horizontal

exposed fault contact (with dip tick)


inferred (certain) fault contact


inferred (uncertain) fault contact

normal fault (u upthrown side, d downthrown side)


reversed or thrust fault (triangle on hanging wall side)


strike slip fault (right-hand displacement)

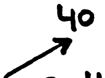

antiform axial surface trace (vertical)


antiform axial surface trace (overturned

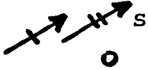

synform axial surface trace (vertical)


synform axial surface trace (overturned

B. *Linear*: fold hinge lines, mineral orientation lineation,, long axes of elongated particles, cleavage-bedding intersection, stretching fabric, pencil sturcture, striae or fibrous crystals on fault surfaces.



azimuth and angle of plunge, basic notation



suggested variations on basic symbol

horizontal

vertical

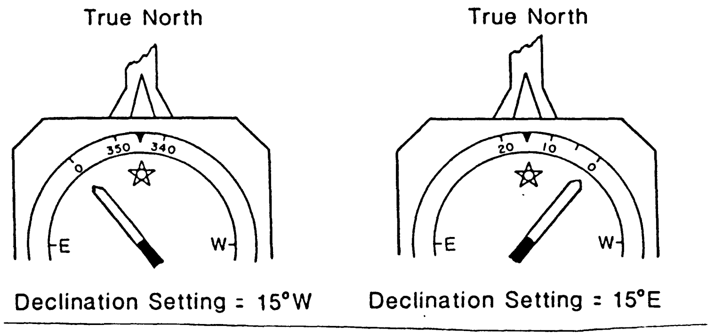


Figure 1. Compass correction for magnetic declination. (a) declination of 15°W, (b) declination of 15°E. Each compass is shown pointing due North. Note that the needle is not parallel to the sides of the compass.

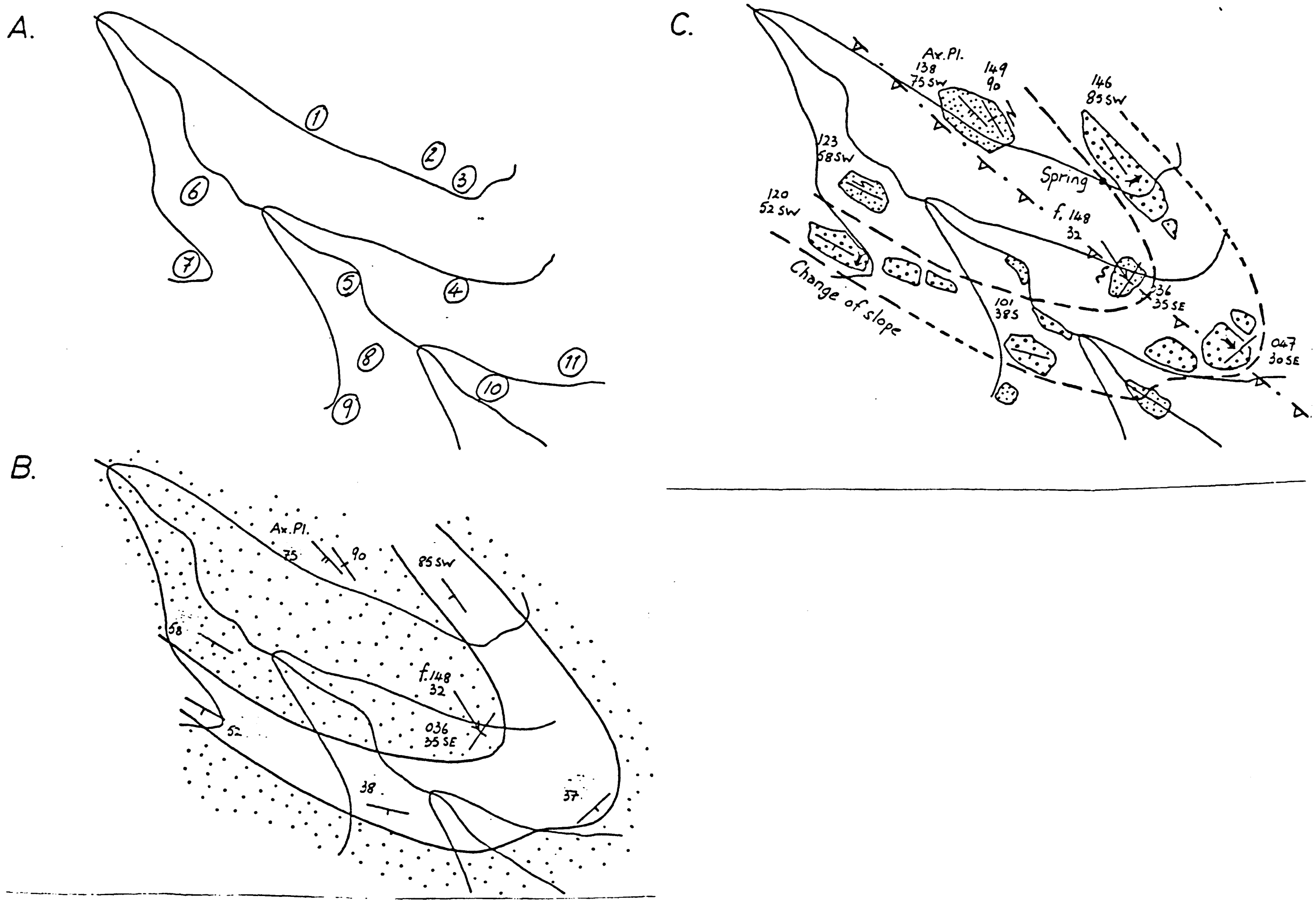
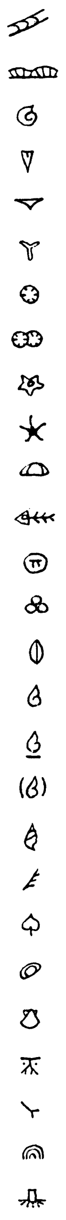


Figure. 2. Types of map record of the same base data. A: records only locality numbers, B: is a solid geological map interpretation and C shows the mapping style recommended, clearly distinguishing facts and inferences.

APPENDIX 9:
Fossil and Structure Symbols for Columnar Sections and Field Notes*



- Algae
- Algal mats
- Ammonites
- Belemnites
- Brachiopods
- Bryozoans
- Corals, solitary
- Corals, colonial
- Crinoids
- Echinoderms
- Echinoids
- Fish bones
- Fish scales
- Foraminifers, general
- Foraminifers, large
- Fossils
- Fossils abundant
- Fossils sparse
- Gastropods
- Graptolites
- Leaves
- Ostracodes
- Pelecypods
- Root molds
- Spicules
- Stromatolites
- Tree trunk in place

- Tree trunk fallen
- Trilobites
- Vertebrates
- Wood
- Beds distinct
- Beds obscure
- Unbedded
- Graded beds
- Planar cross-bedding
- Trough cross-bedding
- Ripple structures
- Cut and fill
- Load casts
- Scour casts
- Convolution
- Slumped beds
- Paleosol
- Mud cracks
- Salt molds
- Burrows
- Pellets
- Oolites
- Pisolites
- Intraclasts
- Stylolite
- Concretion
- Calcitic concretion

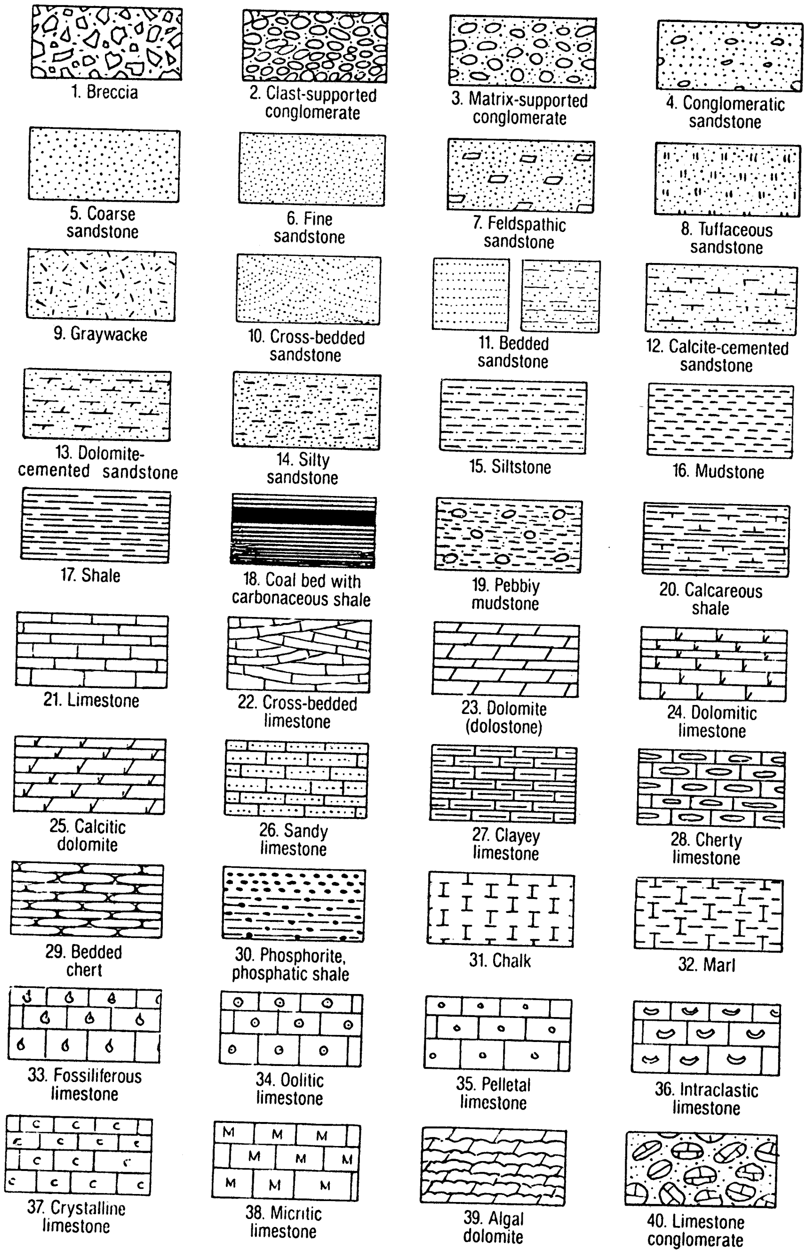
*Chiefly after the *Standard Legend* of the Royal Dutch/Shell Group of Companies (Shell International Petroleum Maatschappij B. V., The Hague, July 1977)

APPENDIX 10: Major Geochronologic and Chronostratigraphic Units in Use by the U.S. Geological Survey[1]

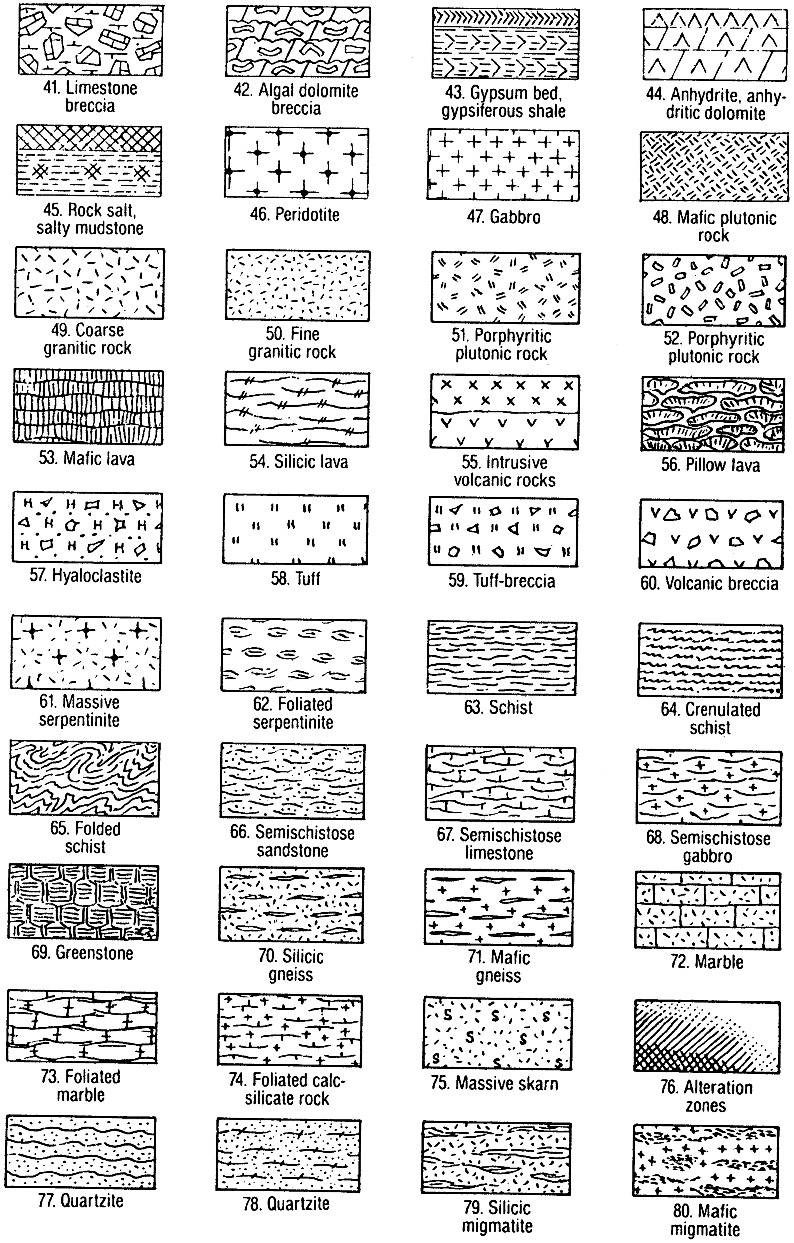
Eon or Eonothem	Era or Erathem	Period or System		Epoch or Series		Age estimates of boundaries in millions of years[2]
Phanerozoic	Cenozoic (Cz)	Quaternary (Q)		Holocene		0.010
				Pleistocene		2 (1.7-2.2)
		Tertiary (T)	Neogene Subperiod or Subsystem (N)	Pliocene		5 (4.9-5.3)
				Miocene		24 (23-26)
			Paleogene Subperiod or Subsystem (Pє)	Oligocene		38 (34-38)
				Eocene		55 (54-56)
				Paleocene		63 (63-66)
	Mesozoic (Mz)	Cretaceous (K)		Late	Upper	96 (95-97)
				Early	Lower	138 (135-141)
		Jurassic (J)		Late Middle Early	Upper Middle Lower	205 (200-215)
		Triassic (Ɍ)		Late Middle Early	Upper Middle Lower	~240
	Paleozoic (Pz)	Permian (P)		Late Early	Upper Lower	290 (290-305)
		Carboniferous Periods or Systems (C)	Pennsylvanian (ℙ)	Late Middle Early	Upper Middle Lower	~330
			Mississippian (M)	Late Early	Upper Lower	360 (360-365)
		Devonian (D)		Late Middle Early	Upper Middle Lower	410 (405-415)
		Silurian (S)		Late Middle Early	Upper Middle Lower	435 (435-440)
		Ordovician (O)		Late Middle Early	Upper Middle Lower	500 (495-510)
		Cambrian (Є)		Late Middle Early	Upper Middle Lower	~570[2]
Precambrian (pЄ)[3] Proterozoic (Ᵽ)	Late Proterozoic[4] (Z)					900
	Middle Proterozoic[4] (Y)					1600
	Early Proterozoic[4] (X)					2500
Archean (A)	Late Archean[4] (W)					3000
	Middle Archean[4] (V)					3400
	Early Archean[4] (U)					3800?
pre-Archean (pA)—an informal time term without specific rank.						4550

1. Format modified slightly from Sohl, N.L., and Wright, W.B. (1980, *Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1979:* U.S. Geological Survey Bulletin 1502-A, p. A1-A3.), with Precambrian units from Harrison, J.E., and Peterman, Z.E. (1980, A preliminary proposal for the Precambrian of the United States and Mexico: *Geological Society of America Bulletin*, v. 91, p. 1128-1133). See these articles for sources of the original data.
2. Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Ages of boundaries not closely bracketed by data shown by ~.
3. A time term without specific rank.
4. Time terms only.

APPEN
Lithologic Patterns for Stratigraphic Columns and Cross Sections

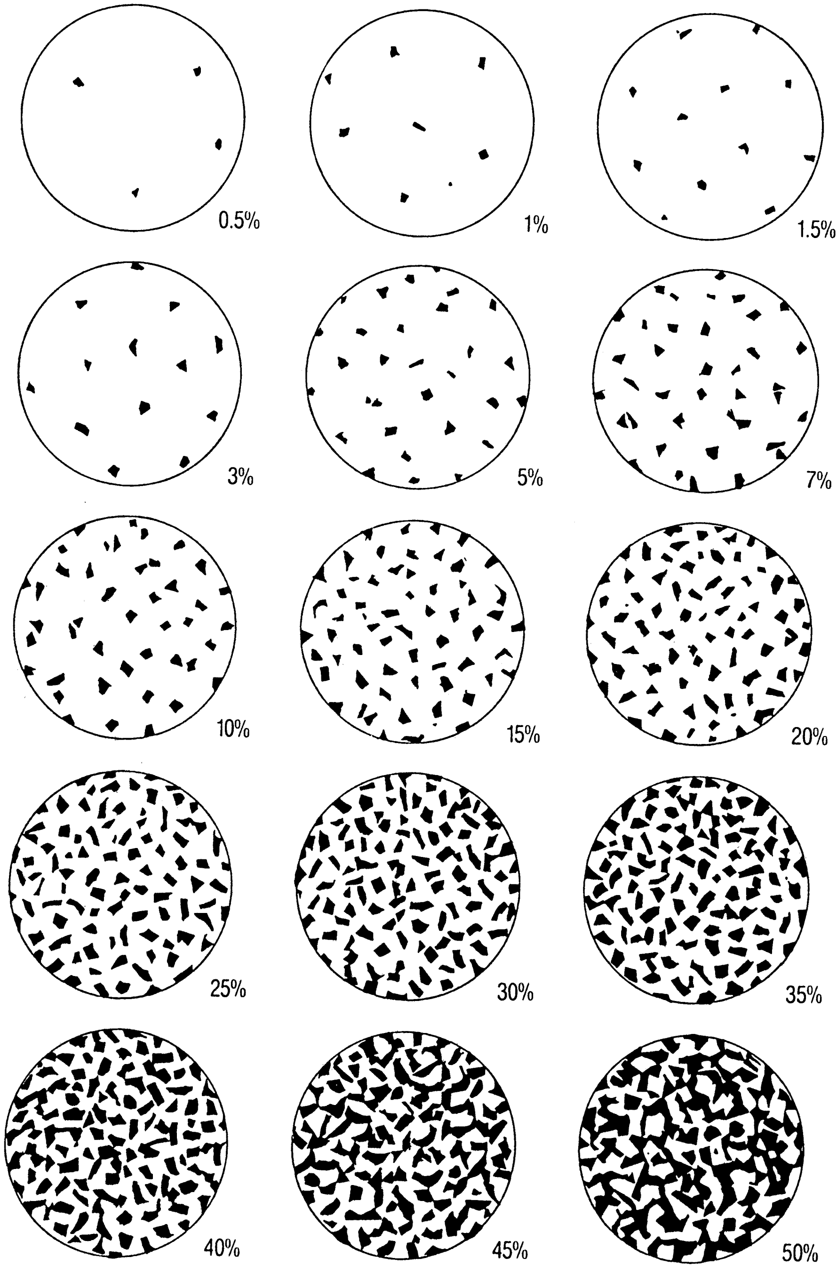


1. Breccia
2. Clast-supported conglomerate
3. Matrix-supported conglomerate
4. Conglomeratic sandstone
5. Coarse sandstone
6. Fine sandstone
7. Feldspathic sandstone
8. Tuffaceous sandstone
9. Graywacke
10. Cross-bedded sandstone
11. Bedded sandstone
12. Calcite-cemented sandstone
13. Dolomite-cemented sandstone
14. Silty sandstone
15. Siltstone
16. Mudstone
17. Shale
18. Coal bed with carbonaceous shale
19. Pebbly mudstone
20. Calcareous shale
21. Limestone
22. Cross-bedded limestone
23. Dolomite (dolostone)
24. Dolomitic limestone
25. Calcitic dolomite
26. Sandy limestone
27. Clayey limestone
28. Cherty limestone
29. Bedded chert
30. Phosphorite, phosphatic shale
31. Chalk
32. Marl
33. Fossiliferous limestone
34. Oolitic limestone
35. Pelletal limestone
36. Intraclastic limestone
37. Crystalline limestone
38. Micritic limestone
39. Algal dolomite
40. Limestone conglomerate

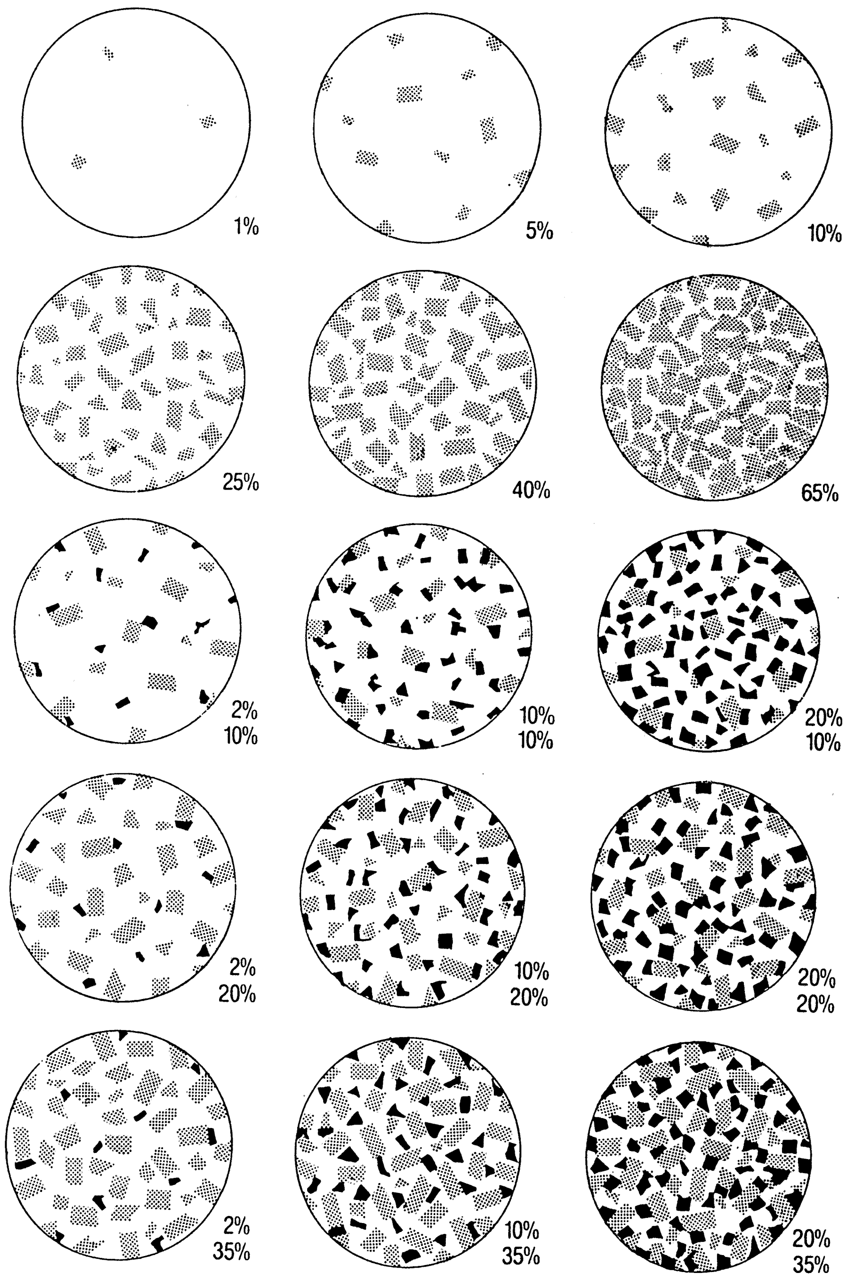


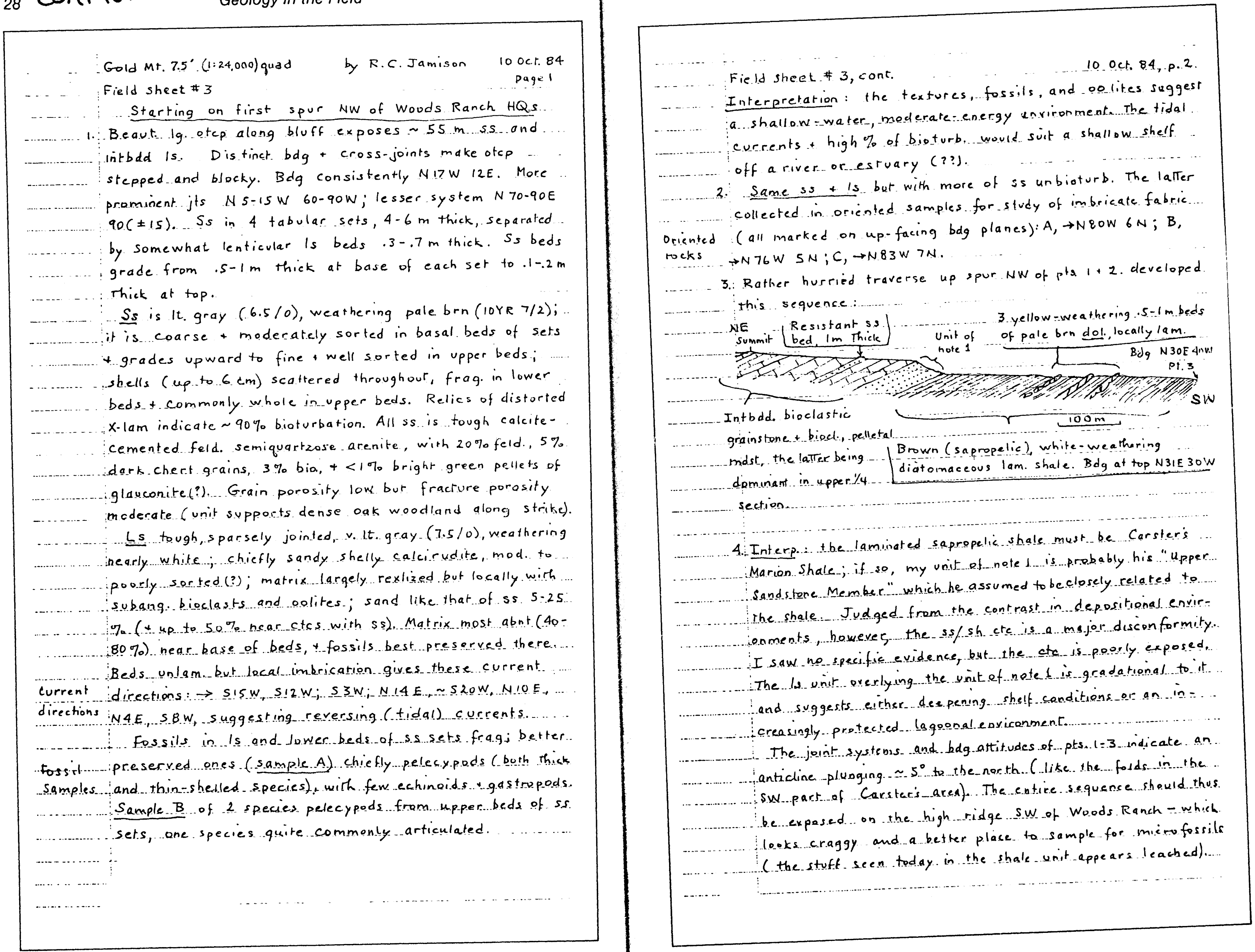
41. Limestone breccia
42. Algal dolomite breccia
43. Gypsum bed, gypsiferous shale
44. Anhydrite, anhydritic dolomite
45. Rock salt, salty mudstone
46. Peridotite
47. Gabbro
48. Mafic plutonic rock
49. Coarse granitic rock
50. Fine granitic rock
51. Porphyritic plutonic rock
52. Porphyritic plutonic rock
53. Mafic lava
54. Silicic lava
55. Intrusive volcanic rocks
56. Pillow lava
57. Hyaloclastite
58. Tuff
59. Tuff-breccia
60. Volcanic breccia
61. Massive serpentinite
62. Foliated serpentinite
63. Schist
64. Crenulated schist
65. Folded schist
66. Semischistose sandstone
67. Semischistose limestone
68. Semischistose gabbro
69. Greenstone
70. Silicic gneiss
71. Mafic gneiss
72. Marble
73. Foliated marble
74. Foliated calc-silicate rock
75. Massive skarn
76. Alteration zones
77. Quartzite
78. Quartzite
79. Silicic migmatite
80. Mafic migmatite

APPENDIX 3. Percentage Diagrams For Estimating Compositon By Volume*



*To convert the results to weight percentages, multiply each volume percentage by the specific gravity of that mineral and recalculate the resulting numbers so that they sum to 100.





Gold Mt. 7.5' (1:24,000) quad by R.C. Jamison 10 Oct. 84
page 1
Field sheet #3
Starting on first spur NW of Woods Ranch HQs.
1. Beaut. lg. otcp along bluff exposes ~ 55 m ss and
intbdd ls. Distinct bdg + cross-joints make otcp
stepped and blocky. Bdg consistently N17W 12E. More
prominent jts N 5-15 W 60-90W; lesser system N 70-90E
90(±15). Ss in 4 tabular sets, 4-6 m thick, separated
by somewhat lenticular ls beds .3-.7 m thick. Ss beds
grade from .5-1 m thick at base of each set to .1-.2 m
thick at top.
Ss is lt. gray (6.5/0), weathering pale brn (10YR 7/2);
it is coarse + moderately sorted in basal beds of sets
+ grades upward to fine + well sorted in upper beds;
shells (up to 6 cm) scattered throughout, frag. in lower
beds + commonly whole in upper beds. Relics of distorted
X-lam indicate ~ 90% bioturbation. All ss is tough calcite-
cemented feld. semiquartzose arenite, with 20% feld., 5%
dark chert grains, 3% bio, + <1% bright green pellets of
glauconite(?). Grain porosity low but fracture porosity
moderate (unit supports dense oak woodland along strike).
Ls tough, sparsely jointed, v. lt. gray (7.5/0), weathering
nearly white; chiefly sandy shelly calcirudite, mod. to
poorly sorted(?); matrix largely rexlized but locally with
subang. bioclasts and oolites; sand like that of ss 5-25
% (+ up to 50% near ctcs with ss). Matrix most abnt (40-
80%) near base of beds, + fossils best preserved there.
Beds unlam. but local imbrication gives these current
current directions — directions: → S15W, S12W; S3W; N14E, ~S20W, N10E,
N4E, S8W, suggesting reversing (tidal) currents.
Fossils in ls and lower beds of ss sets frag; better
fossil samples — preserved ones (sample A) chiefly pelecypods (both thick
and thin-shelled species), with few echinoids + gastropods.
Sample B of 2 species pelecypods from upper beds of ss
sets, one species quite commonly articulated.

Field sheet # 3, cont. 10 Oct. 84, p. 2.
Interpretation: the textures, fossils, and oolites suggest
a shallow-water, moderate-energy environment. The tidal
currents + high % of bioturb. would suit a shallow shelf
off a river or estuary (??).
2. Same ss + ls but with more of ss unbioturb. The latter
collected in oriented samples for study of imbricate fabric
Oriented rocks — (all marked on up-facing bdg planes): A, →N80W 6N; B,
→N76W 5N; C, →N83W 7N.
3. Rather hurried traverse up spur NW of pts 1 + 2. developed
this sequence:

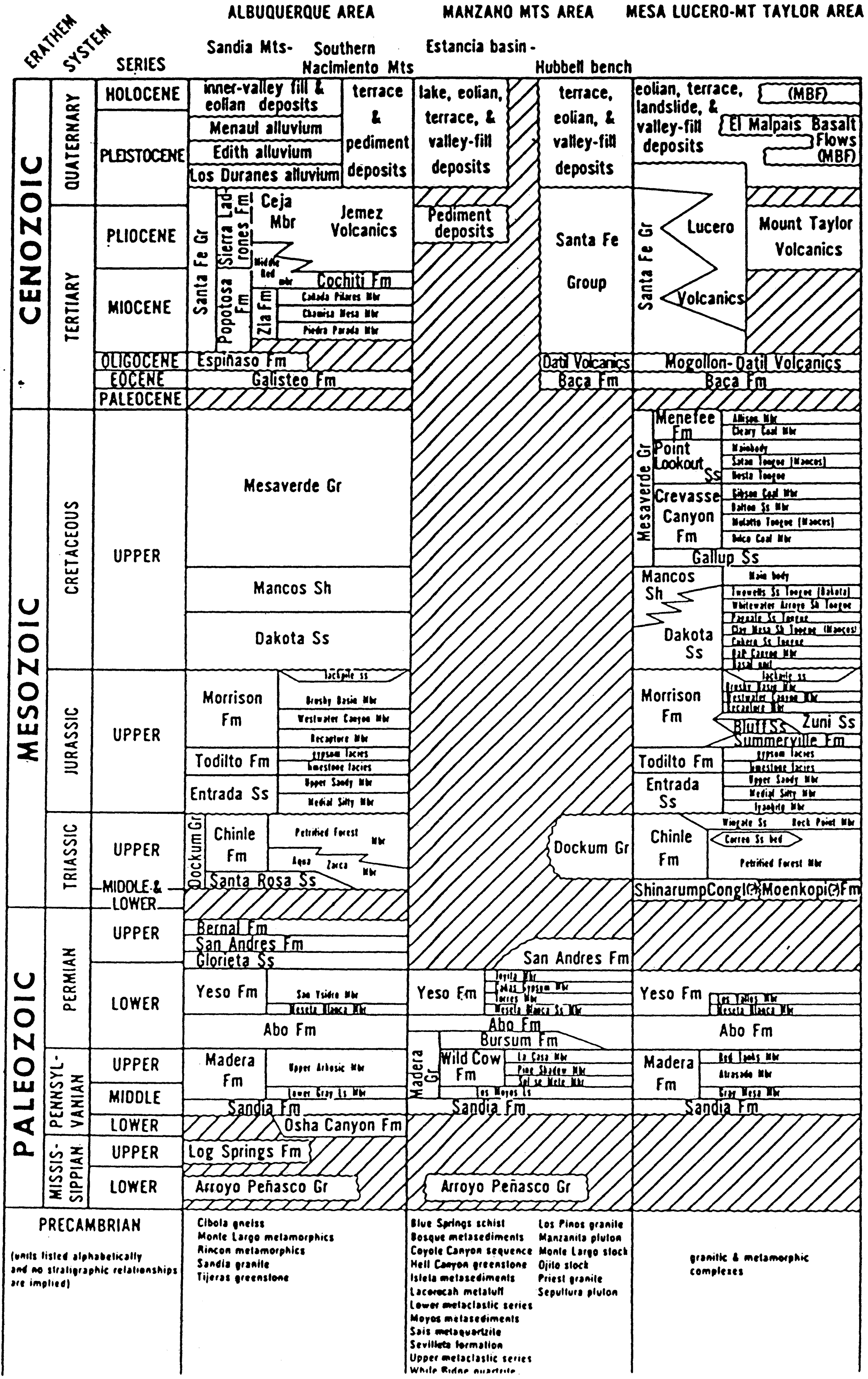
Intbdd. bioclastic
grainstone + biocl., pelletal
mdst, the latter being
dominant in upper 1/4
section.
Brown (sapropelic), white-weathering
diatomaceous lam. shale. Bdg at top N31E 30W

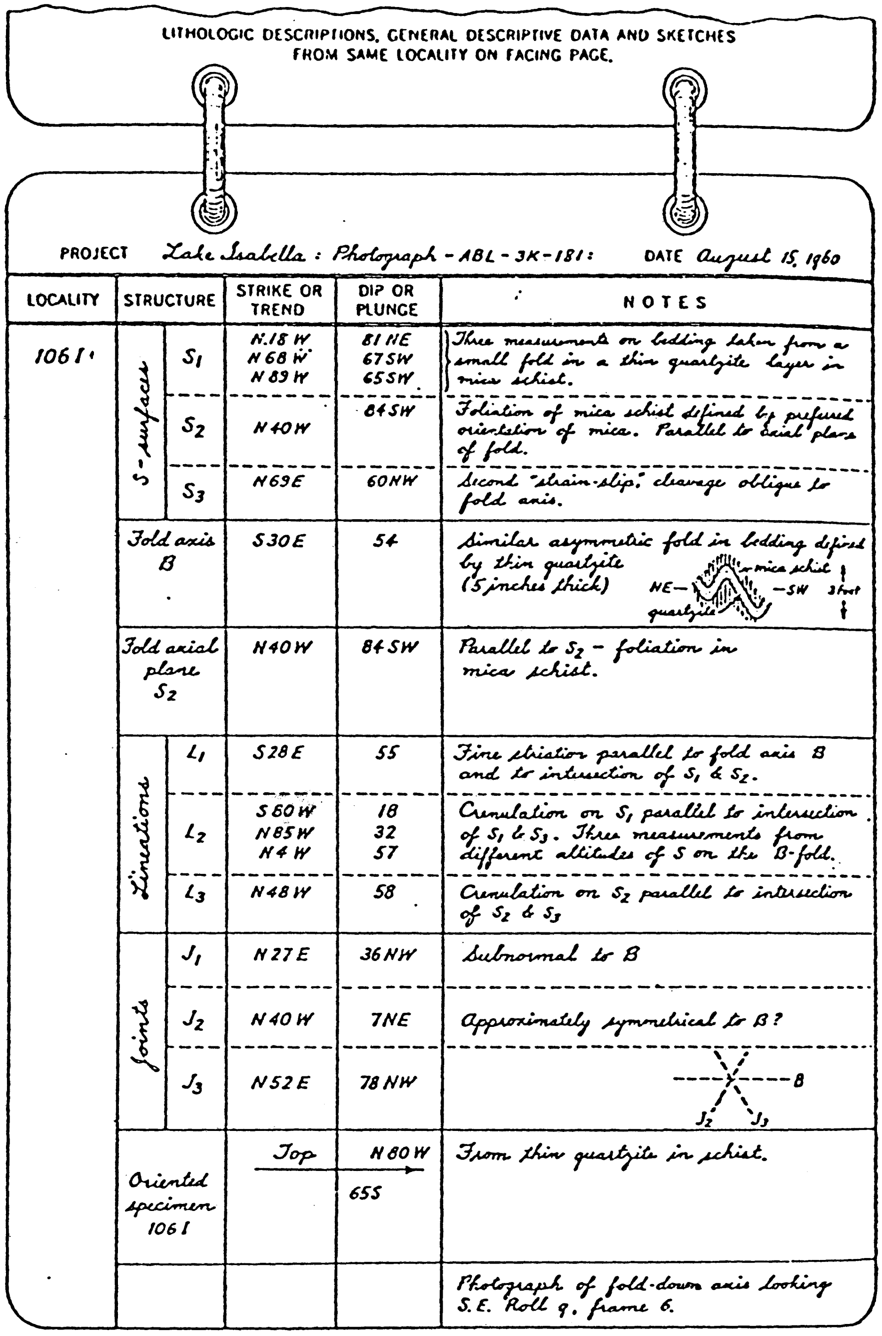
4. Interp.: the laminated sapropelic shale must be Carster's
Marion Shale; if so, my unit of note 1 is probably his "Upper
Sandstone Member" which he assumed to be closely related to
the shale. Judged from the contrast in depositional envir-
onments, however, the ss/sh ctc is a major disconformity.
I saw no specific evidence, but the ctc is poorly exposed.
The ls unit overlying the unit of note 1 is gradational to it
and suggests either deepening shelf conditions or an in-
creasingly protected lagoonal environment.
The joint systems and bdg attitudes of pts. 1-3 indicate an
anticline plunging ~ 5° to the north (like the folds in the
SW part of Carster's area). The entire sequence should thus
be exposed on the high ridge SW of Woods Ranch — which
looks craggy and a better place to sample for microfossils
(the stuff seen today in the shale unit appears leached).

Fig. 3-3. Two pages of field notes, selected to show a variety of entries.

STRATIGRAPHIC NOMENCLATURE CHART

G. Saucier, S. G. Wells, and B. S. Kues





LITHOLOGIC DESCRIPTIONS, GENERAL DESCRIPTIVE DATA AND SKETCHES FROM SAME LOCALITY ON FACING PAGE.

PROJECT Lake Isabella : Photograph - ABL - 3K - 181 : DATE August 15, 1960

LOCALITY	STRUCTURE		STRIKE OR TREND	DIP OR PLUNGE	NOTES
1061'	S-surfaces	S_1	N.18 W N 68 W N 89 W	81 NE 67 SW 65 SW	Three measurements on bedding taken from a small fold in a thin quartzite layer in mica schist.
		S_2	N 40 W	84 SW	Foliation of mica schist defined by preferred orientation of mica. Parallel to axial plane of fold.
		S_3	N 69 E	60 NW	Second "strain-slip" cleavage oblique to fold axis.
	Fold axis B		S 30 E	54	Similar asymmetric fold in bedding defined by thin quartzite (5 inches thick)
	Fold axial plane S_2		N 40 W	84 SW	Parallel to S_2 - foliation in mica schist.
	Lineations	L_1	S 28 E	55	Fine striation parallel to fold axis B and to intersection of S_1 & S_2.
		L_2	S 60 W N 85 W N 4 W	18 32 57	Crenulation on S_1 parallel to intersection of S_1 & S_3. Three measurements from different altitudes of S on the B-fold.
		L_3	N 48 W	58	Crenulation on S_2 parallel to intersection of S_2 & S_3
	Joints	J_1	N 27 E	36 NW	Subnormal to B
		J_2	N 40 W	7 NE	Approximately symmetrical to B?
		J_3	N 52 E	78 NW	
	Oriented specimen 1061		Top	N 80 W 65S	From thin quartzite in schist.
					Photograph of fold-down axis looking S.E. Roll 9, frame 6.

FIG. 4-7. Recommended layout of notebook page for recording of orientation data from a single exposure. Orientations of s-surfaces, lineations, fold elements, and joints are recorded. Descriptive information from the same exposure can be recorded on the facing page of the notebook.

FROM: TURNER & WEISS, 1963, McGraw-Hill

COMMON ABBREVIATIONS

@	At
abnt	Abundant
abv	Above
acic	Acicular
aft	After
aglm	Agglomerate
Alg	Algae (al)
alt	Altered (ing)
amb	Amber
amor	Amorphous
Amph	Amphipora
amt	Amount
ang	Angular
anhed	Anhedral
anhy	Anhydrite (ic)
app	Appear
apr	Apparent
aprox	Approximate (ly)
arg	Argillaceous
argl	Argillite
ark	Arkose (ic)
asph	Asphalt (ic)
bar	Barite (ic)
bcm	Become (ing)
bd	Bed
bdd	Bedded
bdeye	Birdseye
bdg	Bedding
Belm	Belemnites
bent	Bentonite (ic)
bf	Buff
biocl	Bioclastic
biot	Biotite
bioturb	Bioturbated
bit	Bitumen (inous)
bl	Blue (ish)
bldr	Boulder (256 mm +)
blk	Black
blky	Blocky
bnd	Band (ed)
boudg	Boudinage
Brac	Brachiopod
brhg	Branching
brec	Breccia (ted)
bri	Bright
brit	Brittle
brd	Bored
brn	Brown
Bry	Bryozoa
bulb	Bulbous
bur	Burrowed
c	Coarse (ly)
¢	Core
calc	Calcite (areous)
carb	Carbonaceous
Casph	Calcisphaera
cbl	Cobble (64-256 mm)
Ceph	Cephalopod
cgl	Conglomerate
Chaet	Chaetetes
chal	Chalcedony
Chara	Charophytes
chit	Chitin (ous)
chk	Chalk (y)
chlor	Chlorite
cht	Chert
chty	Cherty
Chtz	Chitinozoa
cl	Clastic
cln	Clean
clr	Clear
clus	Cluster
cly	Clay (ey)
clyst	Claystone
cmt	Cement (ed)
cncn	Concentric
cntr	Center (ed)
col	Color (ed)
coln	Colonial
com	Common
conc	Concretion (ary)
conch	Conchoidal
Cono	Conodont
contm	Contaminated
coq	Coquina
Cor	Coral
crbnt	Carbonate
Crin	Crinoid (al)
crm	Cream
crpxl	Cryptocrystalline
ctd	Coated
ctc	Contact
cvg	Cavings
Cyp	Cypridopsis
dd	Dead
deb	Debris
decr	Decrease (ing)
dend	Dendrite (ic)
dess	Desiccation
dism	Disseminated
dk	Dark (er)
dns	Dense (er)
dol	Dolomite (ic)
dolst	Dolostone
drsy	Druse (y)
dtrl	Detrital (us)
Ech	Echinoid
elg	Elongate
Endo	Endothyra
euhed	Euhedral
Euryamph	Euryamphipora
f	Fine (ly)
fau	Fauna
Fe	Iron-Ferruginous
Fe-mag	Ferro-magnesian
fenst	Fenestral
Fe-st	Ironstone
fib	Fibrous
fis	Fissile
fl	Fill (ed)
fld	Feldspar (thic)
flk	Flake
flky	Flaky
flor	Fluorescence
fls	Flesh
flt	Fault (ed)
fltg	Floating
fnt	Faint (ly)
Foram	Foraminifera
fos	Fossil (iferous)
fr	Fair
frac	Fracture (ed)
frag	Fragment (al)
fri	Friable
frmwk	Framework
fros	Frosted
Fus	Fusulinid
Fvst	Favosites
g	Good
Gal	Galeolaria
Gast	Gastropod
gil	Gilsonite
Girv	Girvanella
gl	Glass (y)
glau	Glauconite (ic)
Glob	Globigerina
glos	Gloss (y)
gn	Green
gns	Gneiss
gr	Grain (ed)
gran	Granular
Grap	Graptolite
grd	Grade (ed)
grdg	Grading
grnl	Granule
grnt	Granite
grnt.w	Granite wash
gsy	Greasy
gvl	Gravel
gy	Gray
gyp	Gypsum (iferous)
gywk	Graywacke
hd	Hard
hem	Hematite (ic)
hex	Hexagonal
hi	High
hornbd	Hornblende
hrtl	Horizontal
hvy	Heavy
hydc	Hydrocarbon
ig	Igneous
imbd	Imbedded
imp	Impression
incl	Included (sion)
incr	Increase (ing)
ind	Indurated
indst	Indistinct
Inoc	Inoceramus
intbd	Interbedded
intcl	Intraclast (s)
intfrag	Interfragmental
intgran	Intergranular
intgwn	Intergrown
intlam	Interlaminated
intpt	Interpretation
intr	Intrusion (ive)
intstl	Interstitial
intv	interval
intxl	Intercrystalline
ireg	Irregular
irid	Iridescent
Ivan	Ivanovia
kao	Kaolin
lam	Laminated
lav	Lavender
lchd	Leached
len	Lentil (cular)
lig	Lignite (ic)
lith	Lithographic
lmn	Limonite (ic)
lmpy	Lumpy
lmy	Limy
lrg	Large (er)
ls	Limestone
lse	Loose
lstr	Lustre
lt	Light (er)
m	Medium
magn	Magnetic
magnt	Magnetite
mar	Maroon
mas	Massive
mat	Material, matter
meta	Metamorphic
mica	Mica (eous)
mic	Micro
mky	Milky
mnr	Minor
mnrl	Mineral (ized)
mnut	Minute
Mol	Mollusca
mot	Mottled
mrlst	Marlstone
mrly	Marly
msm	Metasomatic
mtx	Matrix
musc	Muscovite
n	No, none
nod	Nodule
num	Numerous
o	Oil
occ	Occasional
och	Ochre
od	Odor
olvn	Olivine
onc	Oncolites
ooc	Oocast (ic)
ool	Oolite (ic)
oom	Oomold (ic)
op	Opaque
org	Organic
orng	Orange
orth	Orthoclase
Ost	Ostracod
ovgth	Overgrowth
ox	Oxidized
p	Poor (ly)
Para	Paraparchites
pbl	Pebble
pel	Pellet
Pent	Pentamerus
perm	Permeability
pet	Petroleum (iferous)
phos	Phosphate (ic)
piso	Pisolite (ic)
pit	Pitted
pk	Pink
plag	Plagioclase
plas	Plastic
Plcy	Pelecypod
pl	Plant
plty	Platy
pol	Polish (ed)
por	Porous (sity)
pos	Possible (ility)
p-p	Pin point
pred	Predominant (ly)
pres	Preserved (ation)
prim	Primary
pris	Prism (atic)
prly	Pearly
prob	Probable (ly)
prom	Prominent (ly)
prphy	Porphyry
psdo	Pseudo
pt	Part (ly)
ptch	Patch (es)
ptg	Parting
purp	Purple
pyr	Pyrite (ic) (ized)
pyrbit	Pyrobitumen
pyrxn	Pyroxene
qtz	Quartz
qtzc	Quartzitic
qtzs	Quartzose
qtzt	Quartzite
rad	Radiate (ing)
rd	Round (ed)
Ren	Renalcis
repl	Replaced (ing) (men
resd	Residue (al)
rexl	Recrystallize (ation
rhmb	Rhomb (ic)
rmn	Remains (nant)
rr	Rare
rsns	Resinous
rthy	Earthy
rug	Rugose (Rugosa)
s	Small
sa	Salt
sa-c	Salt cast (ic)
S	Sulphur
s&p	Salt & pepper

2/4/86

GEOLOGY 319L

General Geologic Section
Albuquerque Basin Area
(map color in parentheses)

QUATERNARY

Qal---Quaternary alluvium (uncolored); to be used when undifferentiated.

Clay, silt, sand and gravel in active channels and floodplains; thickness up to 10 (?) m.

Qc----Quaternary colluvium (includes talus) (uncolored with black triangles)

Mostly coarse-grained, angular fragments, locally derived; thickness up to 10 (?) m.

Qls---Quaternary landslide deposits (uncolored with solid black circles)

Mostly coarse-grained, locally derived; thickness up to 30 (?) m.

Qtp---Quaternary terrace and pediment deposits (light yellow)

Mostly coarse-grained gravels with clasts of variable age and composition; thickness up to 10 (?) m; Qtpi = oldest deposit, Qtp2 = next oldest, etc.

Qtr---Quaternary travertine deposits (light yellow with black wavy lines)

Light tan, thin to thick bedded; thickness up to 15 (?) m.

TERTIARY

TQsf--Tertiary Santa Fe Group (flesh)

Tan to terra cotta sand, gravel, mudstone, and marly beds; angular to subrounded; thickness up to 3000+ m; (Miocene to Pleistocene) Popotosa Formation (lower formation, fanglomerates) Sierra Ladrones Formation (upper formation, several facies).

Te----Tertiary Espinaso Formation (dark yellow) bluish-gray volcaniclastic breccia, conglomerate, sandstone, and mudstone, volcanic flows, and air/water deposited tuff; thickness averages 440 m.

Tg----Tertiary Galisteo Formation (dark yellow with black slanted lines)

Gray, buff and reddish-brown sandstone and conglomerate, and gray to reddish-brown and purple mudstone; 260 to 1300 m thick. (Eocene)

CRETACEOUS

Kmv ---Cretaceous Mesaverde Group (light brown with green slashes)

Grayish sandstone, dark-brown to black shale, coaly shale numerous coal beds up to 1 m thick; thickness up to 1000 m.

Km----Cretaceous Mancos Shale (dark brown)

Black shale, light-gray to rusty weathering sandstone and siltstone; thin coal beds in upper part and near base; 425 to 600 m thick.

Kd----Cretaceous Dakota Formation (light brown)

Light-gray to buff sandstone and black shale; 1 to 80 m thick.

JURASSIC

Jm----Jurassic Morrison Formation (light green)

Variegated mudstone, sandstone, conglomerate and some limestone; 150 to 280 m thick; Members: Recapture, Westwater Canyon, Brushy Basin and Jackpile (Jmr, Jmw, Jmb, and Jmj, respectively).

Jt----Jurassic Todilto Formation (gray)

Black laminated limestone overlain by gypsum with limestone laminae; 8 to 75 m thick; Gypsum member (Jtg), limestone member (Jt).

Je----Jurassic Entrada Sandstone (light blue)

Buff to tan-brown sandstone; 20 to 50 m thick.

TRIASSIC

TRc---Triassic Chinle Formation (dark green)

Mudstone and lenticular sandstone; variegated in lower part and tan-brown to maroon in upper part; 395 to 650 m thick.

TRs---Triassic Santa Rosa Formation (purple)

Light-gray to reddish-brown sandstone and mudstone; local conglomerate near base; 20 to 130 m thick.

PERMIAN

Pb----Permian Bernal Formation (pink) tan-brown fine to medium-grained sandstone with thin limestone beds; 22-60 m thick.

Psa-Permian San Andres Formation (pink) Two basic members of the San Andres are the Glorieta Sandstone (Psag) and the Bonney Canyon Member (Psab). Glorieta is a clean, white, medium-grained sandstone 20 to 40 m thick; the Bonney Canyon is a gray to black, fine-grained limestone with some interbedded sandstones similar to the Glorieta.

The Glorieta Sandstone is mapped as a formation in places (Pg).

Py----Permian Yeso Formation (orange)
Lower part tan-brown and buff massive sandstone (continuous, even bedding) (Meseta Blanca Sandstone Member, Pym); upper part tan-brown sandstone and gray thin-bedded limestone, locally gypsiferous (San Ysidro Member, Pys); 100 - 180 m thick.

Pa----Permian Abo Formation (red)

Reddish-brown lenticular sandstone and mudstone; locally light-gray sandstone, pellet limestone, and black shale; 210 to 310 m thick.

PENNSYLVANIAN

IPb----Permian Bursum Formation (red with brown slashes)

Reddish-brown, arkosic, hematitic, cross-bedded, locally conglomeratic sandstone with red and gray shales and gram limestones; 12-50 m thick.

IPm----Pennsylvanian Madera Group (Formation) (dark blue)

Gray fossiliferous cherty limestone; dark gray, reddish-brown, and green micaceous and feldspathic shales; green, reddish-brown sandstones; some conglomerate; 140-340 m thick.

Basal formation: Los Moyos Limestone (IPmm), cliff-forming beds of limestone with black to brown chert with minor amounts of black-gray shales and sandstones.
Upper formation: Wild Cow Formation (IPmw), sequences of arkosic sandstone and conglomerate, gray to yellow shales and siltstones, and thin- to thick-bedded limestone.

IPs-----Pennsylvanian Sandia Formation (light blue)

Lower part is highly fossiliferous, light gray to white, arenaceous limestone intercalated shale; upper part light gray to light tan shale; thickness is 22 m.

MISSISSIPPIAN

Ma-----Mississippian Arroyo Penasco Group (dark purple)

Dark-gray massive limestone; locally banded, white or cavernous; some gray shale, locally red; 0 to 30 m thick.

Mpl---Mississippian/Pennsylvanian Log Springs Formation (dark purple)

Ferruginous shales, sandstones, and conglomerates; thickness ranges between 3 and 23 m.

PRECAMBRIAN

p^{Ꞓ}g---Precambrian granite (uncolored with red jackstraws)

Dominantly coarse-grained biotite quartz monzonite and local granite generally with large orthoclase phenocrysts; locally much epidote; includes small areas and xenoliths of gneiss and schist; numerous dikes of aplite and lamprophyre, and a few small, simple pegmatites.

pЄgn--Precambrian gneiss (uncolored with red wavy lines)

Granitic; locally contains mica schist, quartzite and pegmatite or granite.

pЄs---Precambrian schist (uncolored with solid red circles)

Schist with local lenses of quartzite and marble, and dikes of pegmatite and aplite.

pЄq---Precambrian quartzite

319L Map Project Grade Sheet: Name________________________________

1. Mechanics: scale ________
orientation ________________
title________________
neatness______________________

2. Contacts: accuracy ____
types ____
formation recognition ________________________________

3. Structure: strikes and dips: distribution__________ accuracy __________
faults: recognition____________________________
accuracy ____________________________
completeness ___________________________
folds: recongition ___________________________
accuracy____________________________
completeness ___________________________

4. Cross Section:
relationship to map ____________________________
accuracy _______________________________________
mechanics ______________________________________

5. Fieldnotes: completeness__________________ organization ________________
data ______________________ predictions ________________
sketches________________

6. Comments:

GEISSMAN

accuracy in geologic maps

There are two kinds: interpretative and factual. Both are needed

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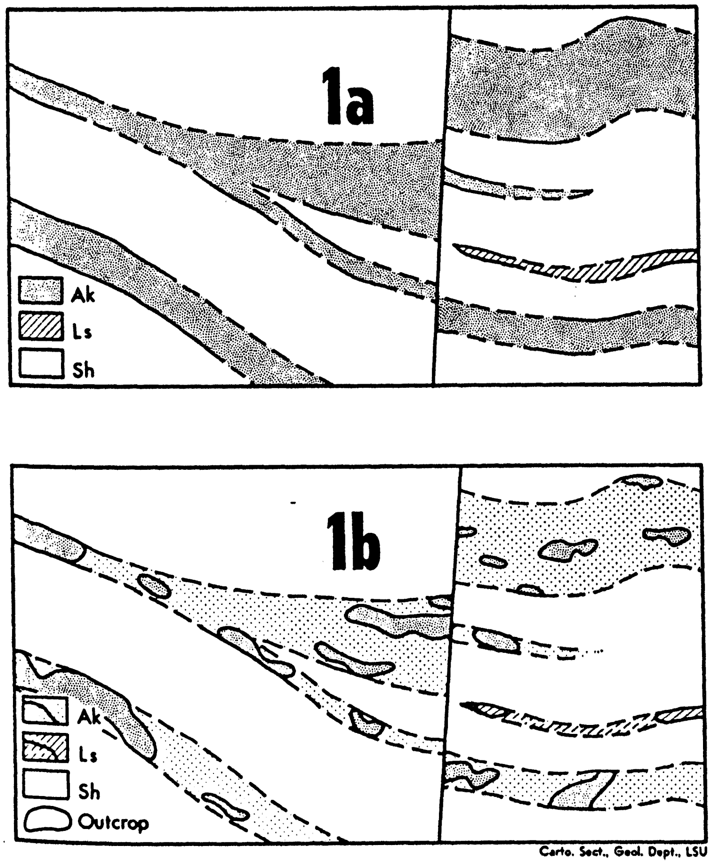


Carto. Sect., Geol. Dept., LSU

1 *These two maps show the geology of a hypothetical area.*
a *A conventional geologic map*
b *An outcrop map*

TWO RECENT PAPERS call attention to contrasting opinions in regard to the accuracy of geologic maps. One (Kupfer 1964) stresses that geologic maps are one of the best sources of factual data and reasonably independent of the fads of geology. Specifically, regional maps in the Wyoming area are cited that were unchanged by the current trend in geologic thought away from large overthrusts to the present concepts of more nearly vertical uplifts. In contrast, Harrison (1963) stresses that geologic maps are highly interpretative, dynamic, and changing, and that 'later generations of geologists will produce maps different from those of today.' He illustrates this point forcefully by two startingly different maps of the same area. The first, produced in 1928 in the heyday of plutonism, shows almost no similarity to the second, produced in 1958 under the dominance of granitization doctrine.

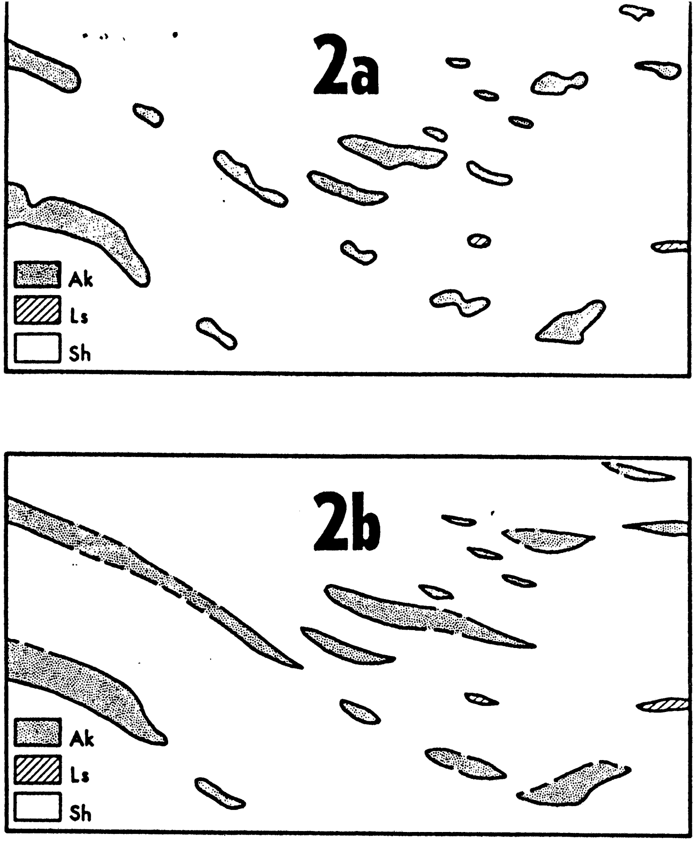
Harrison is correct; most present-day geologic maps are highly interpretative, and as such they must change as geologists develop new ideas and concepts. But I advocate greater use of the more stable kinds of maps that stress accuracy and factual data, and clearly differentiate what is known from what is surmised. Factual maps should not replace interpretative maps, but be presented along with them. Each has its use. Geology, if it is to continue to be a science, and not an art, must adopt more rigorous mapping and publishing techniques.

The point I wish to make can be illustrated by the highly simplified maps shown in figure 1. Figure 1A illustrates the typical geological map. A reader has no idea how accurate the map may be, or how sound the interpretation. If anyone doubts the interpretation he would be obliged to remap the whole area, possibly only to find the original map was essentially correct.

Figure 1B, of the same area, is an *outcrop map*—one of the more factual type of maps I advocate. If detailed geology is being done, it only takes a little more time to make a map of this type, but it has many advantages. For example, it forces the geologist to put down all available data (most good geologists would do this anyway). But the real advantages are not to the geologist doing the mapping, but to the user. When this map is published the reader gets a very real impression of the accuracy and reliability of the map. If the reader has a pet hypothesis, he can see how well the data supports or refutes it. If he wishes, he can even reinterpret the map to suit his own ideas and decide whether it might be worthwhile to do some mapping in the area. If he does visit the area he can go directly to critical exposures and know what he is likely to see.

Outcrop maps are not new or revolutionary. Detailed British maps (four inches to the mile) are commonly outcrop maps. Several maps in the USGS Geological Quadrangle map series use intensity of color to differentiate outcrop from hypothesis, as in the maps by Callaghan and his associates in Utah (GQ 153-156) and by Balk in New England (GQ 92-93). Field geologists should be more aware of this kind of mapping and should strive toward it in detailed studies.

An outcrop map is never strictly factual; all geology is interpretation. The most factual map will contain interpretations as illustrated by figure 2, based on actual mapping. Figure 2A was made by a geologist-in-



Carto. Sect., Geol. Dept., LSU

2 *These outcrop maps show different interpretations of the same area. Both resulted from field mapping in the California Coast Ranges.*

training in an area where exposures were scarce. He had already learned that there is much information between outcrops that can tell the experienced geologist what lies below. He had learned to use those indispensible aids to good mapping: vegetation, topography, gopher holes, soil, hand lens, etc. But in this particular patch of ground there seemed to be little but arkose that cropped out; the ground between strongly suggested shale. The geologist-in-training carefully outlined each outcrop of arkose, showing only what he could see for sure (figure 2A). An experienced geologist, working the same area, interpreted the arkose as resistent blocks caught in a giant gouge zone of mashed clay and graywacke. His map, figure 2B, is more interpretative, but probably also more accurate. Note that even the legend is different.

For a different area, figure 3A shows not only the distribution of the outcrops, but also the soils. It also shows the geologist's interpretation of the area (with color, this can be shown with greater clarity). Figure 3B is a conventional map of the same area. Both assume that a facies of limestone appears between two arkosic phases, but a geologist looking at map 3A could decide that a fault was present and produce a new map showing his interpretation (3C) completely in the office. He could field-check his interpretation with a minimum of difficulty and not have to repeat the laborious task of checking all field measurements. Map 3B, however, could be interpreted as a fault only after additional field work and with detailed explanations in text.

Figure 3 brings out another advantage of the factual map. Publication of map 3C, based on map 3A, needs only a brief note. It confirms and justifies the mapping of the geologist who produced 3A. It proves him to be a trustworthy and accurate map maker whose work is still reliable when new ideas are conceived. In contrast, if map 3B were published first, map 3C could be published and accepted only after long explanations of the differences involved. Its publication would undoubtedly result in recriminations and acrimony between the two geologists involved, and considerable loss of face by whichever one was proved to be wrong. All this would clutter the literature with tens and even hundreds of pages of needless pros and cons.

Factual maps can also help the somewhat maligned image of the geologist held by some specialists in other fields. When engineers or other non-geologists see the highly diverse, interpretative maps produced from the same area (such as figure 1A, 2B, and 3B, or the two maps cited by Harrison), they do not really understand the reason for these legitimate differences in opinion. It is unlikely that they will decide that geology is pure fancy, but rather that geologists are fabricators of tall tales. In that case they will decide to do their own geology so that they will know which rocks occur, and where. But if the several interpretative maps are accompanied by a nonchanging factual map, they can understand the problem better, and more readily see why the same basic data can yield diverse results.

But figures 1 to 3 are hypothetical and oversimplified. For example, even the word 'outcrop' is subject to various interpretations. In some areas bedrock may not be right at the surface, and yet there is no reasonable doubt as to the rock below. For mapping purposes, this might be termed 'outcrop,' but details should be explained in text. Other factors involved may be difficult to put on geologic maps, but we should try. Maps of metamorphic rocks illustrate the problem. Harrison (1963, p. 231) points out that even where a metamorphic rock crops out, it can be variously interpreted as formerly having been an igneous ultramafic or impure limestone. In that case the factual (objective) map should describe the lithology of the rock and the interpretative (subjective) map can show the possible origin. This is exactly what V. J. Hurst (1955) has done on his very fine map of the metamorphic rocks of the Mineral Bluff Quadrangle, Georgia. Lithology, interpretation, and outcrops are all shown. Thus the reader not only has the advantage of the reasonably clear and simple interpretation of a competent field geologist to help him understand a complex series of rocks, but also he can see the field data it is based on. Future geologists are free to agree or disagree without recourse to the field.

There are many other examples of data that may, at first seem to be unmappable. Is an isolated sandstone outcrop lithologically more like formation W or Z? The fact that it is sandstone can be shown on the map, but the subtle reasons why the author chooses W and not Z probably cannot be shown. Or in a facies change from shale to sand, at which outcrop is the symbol for sandy shale to be dropped and the one for shaly sand to be used? If an arkose is deposited on a deeply weathered granite surface, which outcrops are igneous and which sedimentary? Thus, even at best, an outcrop map contains interpretation, but it is a step in the right direction. Even here, an ingenious geologist may invent symbols that will give readers some idea of fact versus interpretation.

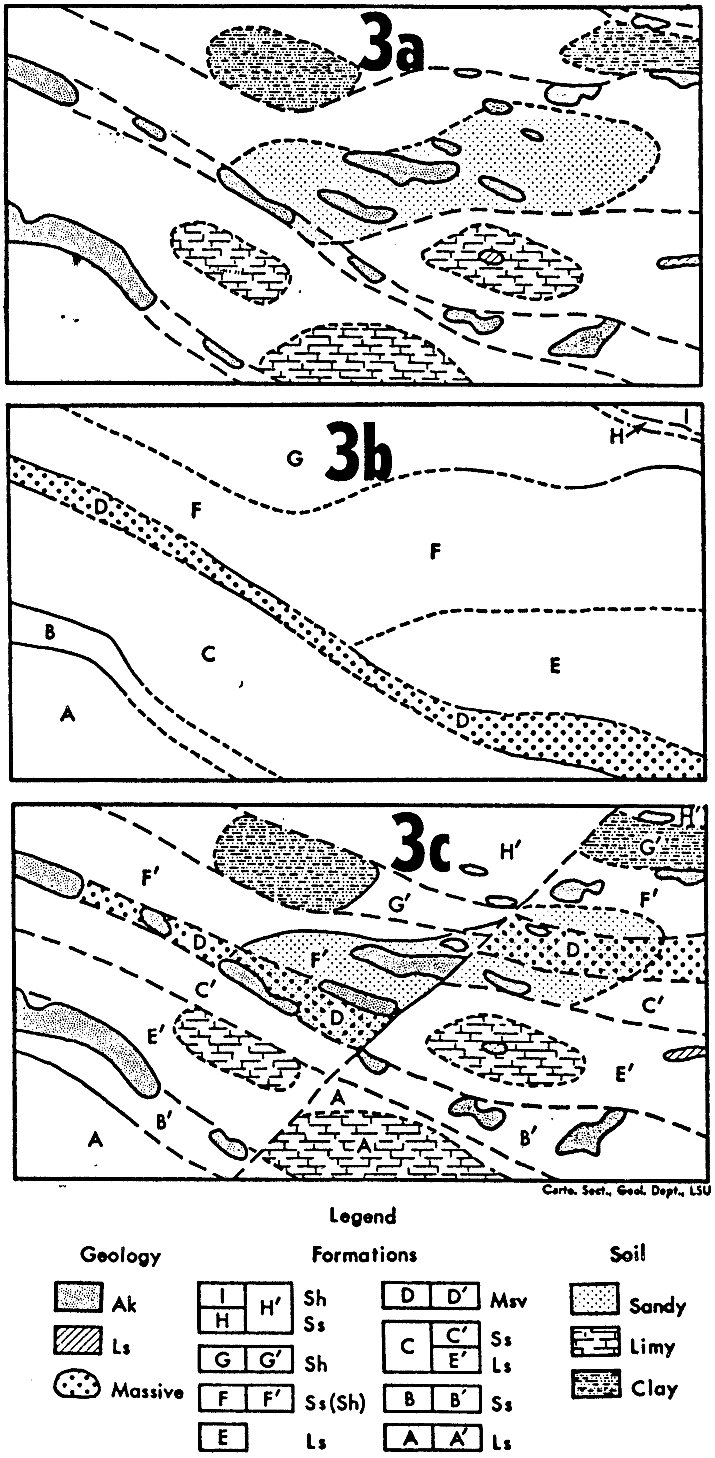
So far this paper has been concerned with factual maps that show outcrops, soils, and lithology. There are many other kinds of objective maps. Whether a map shows rocks, ages, structure, stratigraphy, soils, economic possibilities, or seismic data, every effort should be made to give readers a clear picture of the data involved as well as its interpretation. As we do this and learn to do it better, clearer, and more accurately, we will find our own thinking is also clearer and more accurate.

Accuracy and objectivity can also be obtained by rigorous conformity to present mapping conventions. We must use conventional symbols with their conventionally implied accuracy. Dip and strike symbols should be placed so that the point of observation is at the point of intersection. Symbols measured at the outcrops should be differentiated from those taken from air photos and from those taken by long-distance observations of a long line of outcrops (all are legitimate methods and each is highly accurate—but they have different meanings).

The use of solid, dashes, dotted, and queried lines for contacts, faults, etc help differentiate fact from hypothesis. One well-established convention is that a solid line is used if the contact is known and located with such accuracy that its position is fixed to be within twice the width of the solid line in either direction. This means that the geology must not only be well exposed, but the geologist must know exactly where he is on the map, and the map itself must be accurate. The dashed-line contact indicates that position is less well established. The dotted line is for a contact concealed under a younger unit that is shown on the map by a special pattern; a contact crossing under mapped alluvium can be shown by a dotted line. Question marks can be inserted along any contact (solid, dashed, or dotted) to indicate that the contact is interpretative and may not exist. Problematical faults should be indicated by question marks.

Interpretative geolgic maps have made major contributions to our knowledge and will continue to do so. The reason that men like G. K. Gilbert, F. L. Ransome, and N. H. Darton were able to map so much geology, so well, and in a way that even today these maps are still considered to be essentially correct, is that they interpreted what they saw. Those early pioneers did not look at every outcrop and map every bend, attitude, and lithologic change. They saw the whole picture and were able to synthesize a geologic map that was largely correct from a minimum of data. This 'ability to reach valid conclusions by meticulous observation of fragmentary evidence, . . . [and] to extrapolate a reasonable projection beyond available data,' is still a primary trait of a good geologist. (Anonymous quote from *Geotimes*, v. 8, no. 5B, p. 4, 1964)

In this age of quantification, specialization, and computers, this ability to interpret from diverse observations in many fields is possibly the one major difference between geology and many of the sister sciences. Field



3 *This hypothetical map illustrates map patterns from soil and outcrop data; the outcrop data is the same as in the first two figures, but in a new geologic environment.*
a *Outcrop map with soil types and facies interpretation*
b *Conventional geologic map with facies interpretation*
c *Outcrop map with soil types and fault interpretation*

Facies interpretation	Fault interpretation
I *shale*	
H *thin sandstone*	**H'** *sandstone and shale*
G *main shale, some sandstone*	**G'** *shale (restricted)*
F *sandstone and shale*	**F'** *sandstone (restricted)*
E *main limestone*	**E'** *main limestone*
D *massive sandstone*	**D'** *massive sandstone*
C *limestone and sandstone*	**C'** *sandstone (restricted)*
B *massive sandstone*	**B'** *sandstone*
A *lower limestone*	**A'** *lower limestone*

breed of scientific non-specialists, the 'naturalists.' In geology, it is still clear that more is unknown than is known. Geologists must extrapolate from the small fraction of one per cent of the Earth's exposures that are clear-cut outcrops to the rest of the Earth's surface, its interior, the floors of the oceans, and now even to the Moon and Mars. Let us hope they are doing it as well as those giants of the past did their job.

Nor are interpretative maps to be confined to regional mapping. Even the most detailed job in which outcrops are abundant and continuous must be interpreted. The more experienced the geologist, especially with the rocks in the particular area of interest, the better his interpretation will be. Without this interpretation geology will stagnate. This paper is a plea for more interpretive maps as well as for more factual maps. But we must realize that if a particular piece of mapping is worth months of field work and report writing and 30-60 pages of printed text, it may also be worth two published maps. The first should be as objective as possible, showing (to the extent scale and legibility will permit) outcrops, lithology, soils, topography, and other significant factual data. The second should be the best possible interpretation of this data, and this must be made by the man who did the mapping, as only he knows the thousand and one minor details that cannot appear on the map or in the text.

In summary, Harrison is right. Our geologic maps are interpretative and do have to change with our ideas. But we must also record our data in as factual a manner as possible, clearly differentiating that part acceptable to all geologists from that which is more indefinite. The question is not whether we should publish only one or the other of the maps shown in Harrison's figure 1 (1963), or only an outcrop map of the same area; we should publish all three. We now have two, but where do we have a very carefully constructed map showing what lithology is present at each point of outcrop in the area and the probable distribution of these rock types in the areas of poorer exposure? This reasonably factual map, if available, could be used to produce either of the two maps in Harrison's figure, depending on the geologist's *pontif* or *soakist* proclivities. It could even be used by later generations of geologists with *futuristic* proclivities to produce their maps. As it is now, they are going to have to get out their jetmobiles and remap it again. Which is fine, if in the meantime someone hasn't built a spaceport over the critical outcrops.

References

James M. Harrison, 1963, Nature and significance of geologic maps: in *The fabric of geology*. C. C. Albritton, editor; Freeman Cooper & Co., Stanford, 374 p.

V. J. Hurst, 1955, *Stratigraphy, structure, and mineral resources of the Mineral Bluff Quadrangle, Georgia:* Georgia Geol. Survey, Bull. 63, 137 p.

Donald H. Kupfer, 1964, Linear and Curvate Mountains (abstr.): Geol. Soc. America Sp. Paper 82, *Abstracts for 1964* (1965), p. 302.

Dr Kupfer thanks James M. Harrison and George I. Smith for thoughtful criticism.

Geology of sand and sandstone

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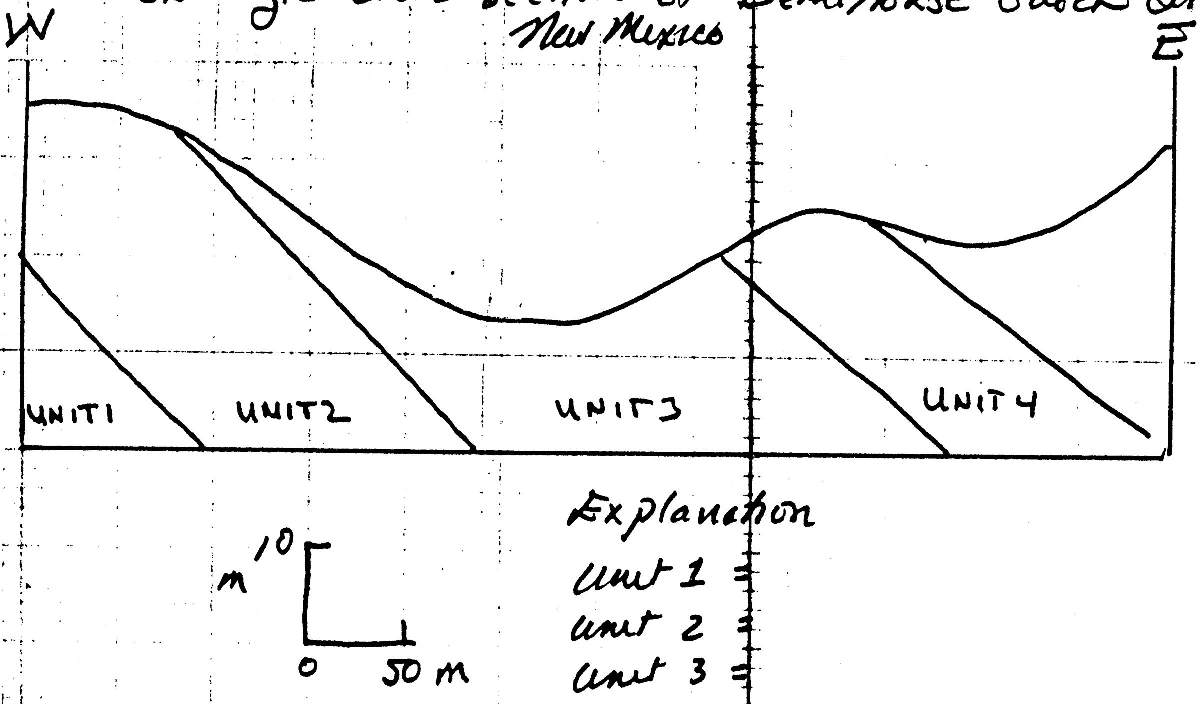
A FIVE-DAY CONFERENCE entitled Geology of Sand and Sandstone was held Oct. 17-22 at Indiana University, sponsored by the Indiana Geological Survey and the Department of Geology of Indiana University. Conference leaders were Francis J. Pettijohn, Raymond Siever, and I. Unlike many recent conferences this conference was self-sustaining.

The objectives of the conference were to give the participants an integrated review of present knowledge of sand and sandstone and to discuss new developments. Applications of hydraulics, thermodynamics and phase equilibria, and statistics and probability were presented and discussed. Among the topics covered were mineralogy and provenance, texture, classification, petrographic analysis, primary sedimentary structures, sedimentary mechanics, chemical composition and diagenesis, sand bodies, field study of sedimentary structures and bedding, internal organization of sand bodies and the broader topics of chemical controls on fluid and rock composition, environments of sand deposition, and sedimentary associations and basin analysis.

Lectures, informal discussion, two petrographic laboratory sessions, and a sedimentary structure field trip were used to present this material. The field trip was particularly useful because it permitted the participants to evaluate in the field many of the concepts that had been developed beforehand in lectures. The field trip was also timely, since coming on the fourth day it very effectively provided a change from lectures. The conference was not a research conference, where specialized experts gathered to discuss specific topics. Rather it was held at a high level with the specific intention of imparting as much material as possible in five days.

There were 55 participants, 12 of them from outside the United States: from Argentina, Canada, France, Surinam, and Venezuela. Seven participants worked for governmental surveys, 24 were from universities, 22 were from the petroleum industry, and two were from the sand industry.

Geologic Cross-section of Deadhorse Gulch Area
New Mexico



Name Date Page #

Project

Station 1:

- location
- observations
- measurements
- inferences
- predictions

Observations between Sta 1 & 2:

STATION 2:

Summary: Major aspects of day's work
"abstract of field day"

Table 1. Summary of fault data, Deadhorse Gulch, NM

Fault #	ORIENTATION	DIP	Characteristics