Chapter 7 Paleofacies Reconstructions

A mighty odd term is the facies.
It seems no one knows how to use it,
and yet of the study-
most geologists make it the bases.

INTRODUCTION

In chapter one through six, we focused on learning to describe sedimentary rocks and sedimentary sequences, and to compile and present these observations in graphic formats. The first of these skills forms the basis for interpretation of sedimentary processes. The second allows stratigraphers to visualize lateral and vertical relations between adjacent units and to construct various facies models. Accomplishment of these two goals, gaining an understanding of depositional processes by examination of sedimentary sequences and gaining an understanding of geometric and temporal relationships on the regional scale, provides stratigraphers with the necessary tools to interpret ancient environments and decipher earth history.

Many texts, and even more articles in professional journals, have been written on the interpretation of depositional processes and environments from analysis of textures, structures and geometries of sedimentary deposits. The ability to integrate bits and pieces of data into meaningful stratigraphic and environmental interpretations can take years of practice to master. Stratigraphy students who pursue this discipline will undoubtedly become familiar with the concepts of facies modelling, presented in many works including those by Reineck and Singh (1980), Davis (1983), Walker (1984) and Reading (1986) who give a thorough treatment of facies modeling. In this chapter we will introduce some of the ways stratigraphers present the results of their studies after the depositional processes and environments have been deciphered. Paleofacies, paleogeographic, paleogeologic and isopach maps are some of the end products of the processes that began back on the outcrop with the description of such seemingly insignificant parameters as rounding of sand grains and style of cross bedding.

PALEOFACIES AND PALEOGEOGRAPHIC MAPS

The term facies has been widely used in geology and sedimentology. The term was first thoroughly described by Walther (1893-1894) who discussed the relationship between time equivalency and lithologic equivalency. Walther argued in his Law of Facies that a vertical succession of strata would be formed by the lateral migration of adjacent environments. At least two slightly different aspects of the term can be found in the literature. Some use the word facies to refer to a particular depositional environment where there is a correlation between processes and the type of sediment produced. Thus, one can speak of the beach facies, point bar facies or alluvial facies. Various facies are then grouped into **facies models**. Other studies use the term in a more restrictive sense and refer to sandstone facies, limestone facies and the like. Various authors such as Miall (1978) have referred to this use of the term as **lithofacies** and defined a number of codes that are useful for rapid description of sedimentary rocks in the field (Table 7.1).

Facies Code	Lithofacies	Sedimentary Structures	Interpretation
Gms	Massive, matrix-supported gravel	Massive bedded	Debris flow
Gmu	Massive, unsorted, clast-supported gravel	Normal-inverse graded crudely bedded, no fabric or inbrication	Debris flow
Gm	Massive or crudely bedded gravel	Horizontal bedding imbrication	Hyperconcentrated stream flow, sieve deposits, lag, bars, sediment flow
Gt	Gravel, stratified	Trough cross beds	Channel fill
Gp	Gravel, stratified	Planar cross beds	Linguoid bars or deltaic growth from older bar remnants
St	Medium to very coarse grained sand, may be pebbly, possible volcanic grains	Solitary or grouped trough cross beds	Lower-flow regime dunes
Sp	Medium to very coarse grained sand, may be pebbly	Solitary or grouped planar cross beds	Linguoid, transverse bars, sand waves, lower-flow regime
Sr	Sand, very fine to coarse	Ripple marks	Ripples
Sh	Very fine to coarse grained sand, pebbles	Horizontal lamination	Planar bed flow, upper and lower flow regime
Sl	Sand, fine	Low-angle cross beds (less than 10°)	Scour fills, crevasse splays, antidunes
Se	Erosional scours with intraclasts	Crude cross bedding	Scour fills
Ss	Sand, fine to coarse	Broad, shallow scours including eta cross-stratification	Scour fills
Sse, She, Spe	Sand	Analogous to Ss, Sh, Sp	Eolian deposits
Fh	Silt, mud, ash	Crude horizontal bedding	Planar bed flow, traction carpets
Fl(a)	Sand, silt, mud (ash)	Fine lamination, very small ripples	Overbank, waning flood deposits
Fsc	Silt, mud	Laminated to massive	Backswamp deposits

Table 7.1. Lithofacies codes derived from sedimentary structures and interpretation of fluvial and volcaniclastic deposits. Fluvial codes from Miall (1978) with addition of various codes for volcaniclastic deposits from Fritz and Harrison (1985).

Two main points concern us here: 1) facies are distinguished by aspects detectable in the field and defined by objective criteria; 2) facies will ultimately be given an environmental interpretation. Point 1 forms the conceptual basis for facies and paleofacies maps. The construction of maps delineating the distribution of facies is based on observational data and should involve subjective interpretation only in the sense of defining boundaries and naming individual facies. We will address the subject of paleofacies' map construction below. Point 2 applies to how paleofacies maps are interpreted during environmenta analysis. For example, the laminated silt facies on a paleofacies map may become the prodelta environment on a paleogeographic or paleoenvironmental map. We will confine our treatment to the conceptual, mechanical and graphic aspects of constructing such interpretations, rather than to the methods of interpretation.

Although the nature of the information displayed on paleofacies and paleoenvironmental maps differ fundamentally (one is descriptive, the other interpretive), the mechanics of their construction are identical. Both maps use time slices, based on chronostratigraphy or biostratigraphy, through two or three dimensional stratigraphic models (cross sections or fence diagrams) as their data base. The idea is to imaginatively "shave off" the top of the correlation (or fence) diagram at a desired time-stratigraphic horizon. The stratigrapher then shifts perspective to the third dimensional so as to look down onto the top of the diagram and gain a "snapshot" of an instant in geologic time. Of course, by looking down onto a fence or correlation diagram, all one would see would be lines. The trick, therefore, becomes filling in the spaces between the lines with appropriate lithologies, facies or environments.

Figure 7.1 shows how this is done from a simple fence diagram, using a volcanic ash bed as a time-stratigraphic marker. The first step is to pencil in the lithology just below the ash bed at each individual station. Stations 1 and 2 were sites of sand deposition at this time while mud was being deposited at site 3. Somewhere between Stations 1 and 3 and Station 2 and 3 there must be sand-mud contacts. Rather than arbitrarily putting the contacts anywhere, go back to the fence diagram and see where the ash bed crosses the contact (but remember that you already arbitrarily placed it at this point when the fence diagram was constructed). Between Stations 1 and 3, the intersection lies pretty close to 1. Between 2 and 3 the intersection occurs nearly halfway between the two. On the map, connect these two points to form a facies or environment boundary. Obviously, with two dimensional cross sections it is impossible to draw facies maps, other than a narrow strip along the cross section. In other words, the resultant facies map will be necessarily simplistic, and the trends of boundaries between facies will be unknown.

Like all formally presented stratigraphic. work, maps should contain titles, scales, legends if necessary, name, and sources of data. Figure 7.2 shows examples of paleogeographic maps.

BLOCK DIAGRAMS

Block diagrams are even further interpretations of stratigraphic data than paleogeographic maps. They are really nothing more than paleogeographic maps extrapolated to the third dimension. Block diagrams are attractive because in addition to showing the surface distribution of sediments or environments, their side panels give a schematic representation of the system's recent progradational or retrogradational history. Block diagrams are a nice way of combining chronostratigraphy and lithostratigraphy into the same figure and presenting a complete interpretation of the environmental interpretation through time. The tops of block diagrams are constructed just like paleogeographic maps. The side panels, although designed to portray lithostratigraphic cross sections, are usually simplifications of those cross sections. An example of such a block diagram is presented in Figure 7.3.

PALEOGEOGRAPHIC MAPS

In some stratigraphic studies, it is desirable to know the distribution of rocks below a certain unit. This may especially be true where a large unconformity underlies the unit and the subajacent strata are varied, diverse and perhaps deformed. Maps created with the intention of showing rocks underlying a unit are called paleogeographic or geologic sub crop maps. Ideally, these maps are drawn from time-stratigraphic surfaces, the sub-Mississippian paleogeography, for instance. In practice, though, these maps are often drawn below lithostratigraphic surfaces, such as the Madison Limestone for example. Although the second procedure is technically incorrect, it is often a close approximation where large unconformities are involved. Paleogeologic maps are

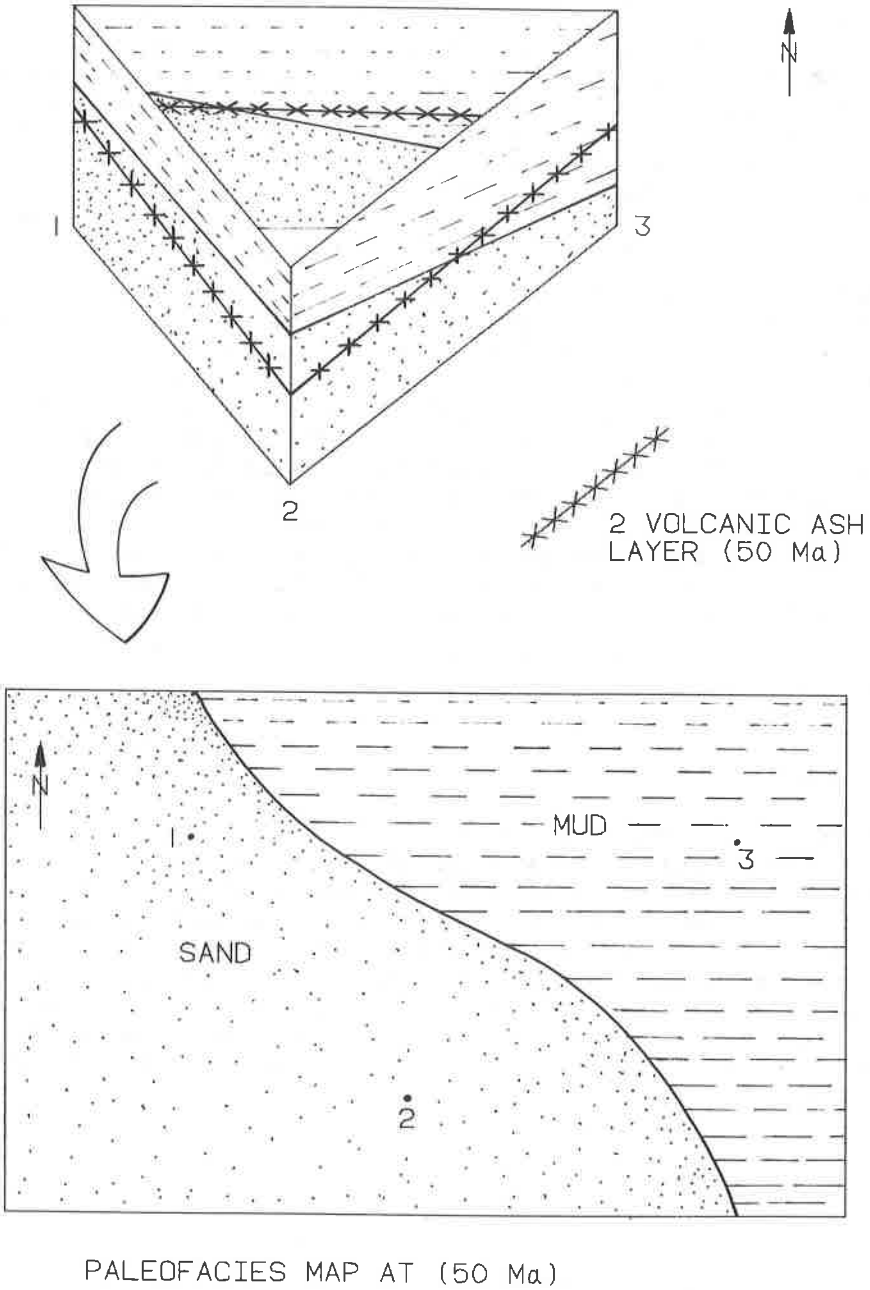

Figure 7.1. Fence diagram and paleofacies map at a specified time horizon.

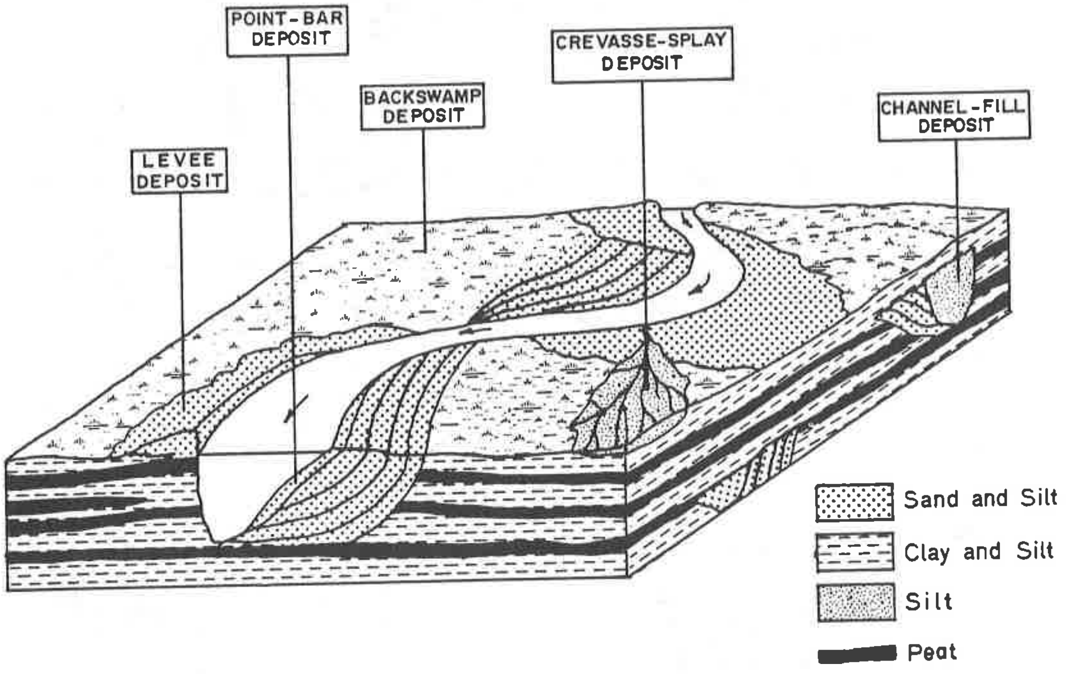

Figure 7.3. Block diagram of a fluvial depositional model for Bullion Creek and Sentinel Butte Formations, North Dakota. From G. H. Groenewold and others, 1981, Depositional setting and groundwater quality in coal-bearing sediments and spoils in western North Dakota, in, F. G. Ethridge and R. M. Flores, eds., *Recent and ancient nonmarine depositional environments: models for exploration*, v. 158, Fig. 2, Society of Economic Paleontologists and Mineralogists Special Publication No. 31. Reprinted by permission of SEPM.

ISOPACH MAPS

Isopach maps show total thickness of a given lithostratigraphic unit. Isopach maps make no contentions about how much of the contour pattern reflects subsequent erosion versus initial depositional geometry. However, because the contours are drawn from a limited number of data points, there are always some subjective decisions made my the mapmaker. Usually, these are not crucial decisions, but once in a while they can be made to sway the readers mind one way or the other. Take, for example, a group of thickness points that seem to approach zero in the proximity of a known fault. One geologist, who happens to believe that the fault was active only before sedimentation took place in the basin, would be tempted to wrap closely spaced contours around parallel to the fault, implying that there was a steep slope at the edge of the basin during deposition. Another geologist, one who believes that the faulting post dated sedimentation, might truncate his contour lines into the fault, indicating that some of the thinning at that edge was due to later uplift and erosion. In general, the precision of the map is a function of the number of data points.

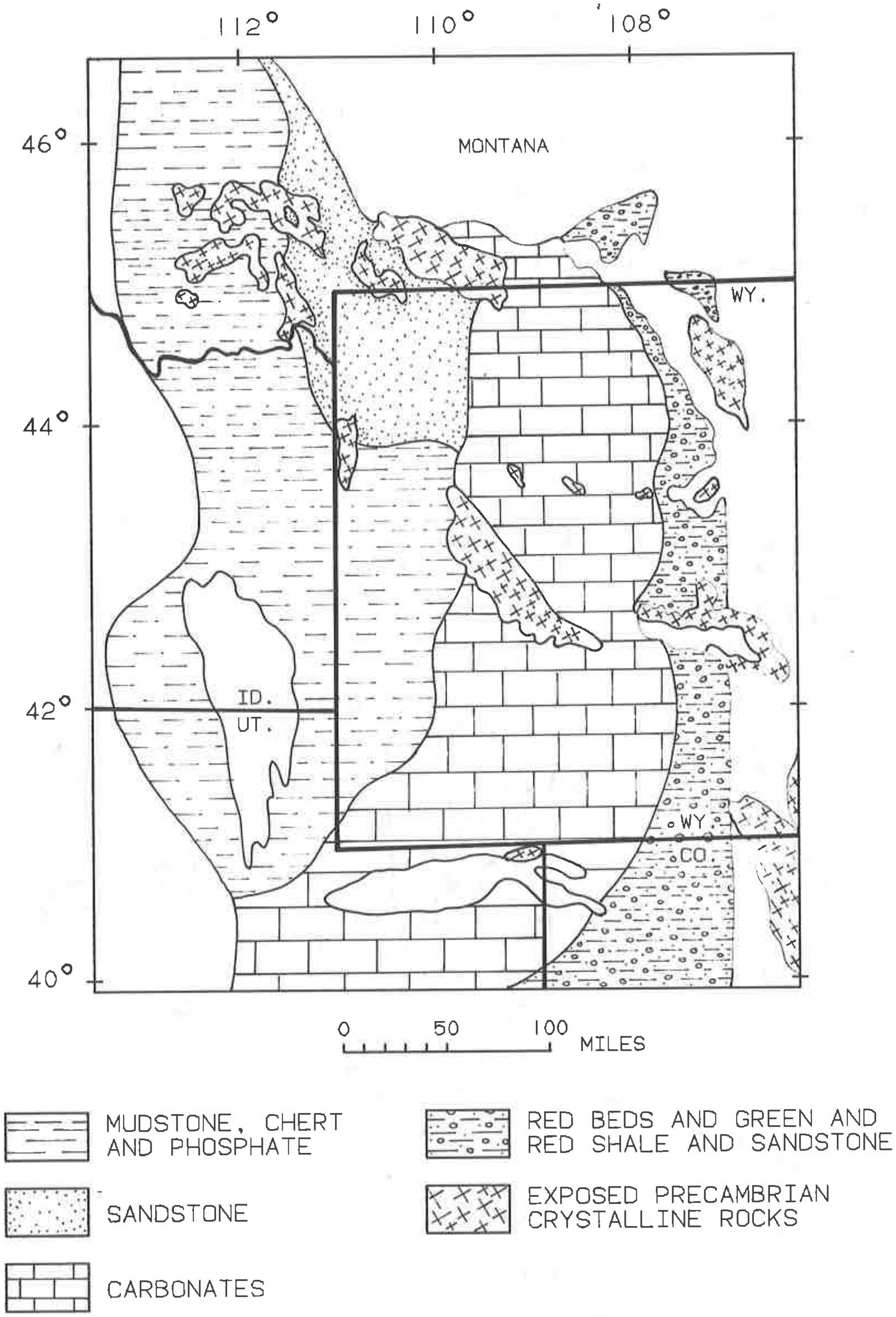

Figure 7.4. Paleogeographic map of the Permian Phosphoria Formation and equivalent age rocks.

To make an isopach map, plot thicknesses of a desired stratigraphic interval as numbers next to the point on the base map that represents the location of the measured section or bore hole log. After all the known stations have been plotted, decide on the contour interval that would make the best map. In other words, if all the thicknesses lie between 48 and 107 feet, it would be useless to have a contour interval of 100 feet. Likewise, it would probably be too confusing to have contour intervals as small as 1 foot. Depending on the station spacing and control (number of data points), a contour interval of 5 or 10 feet would probably be best. After the contour interval has been decided upon, start at a point that will have a contour going right through it (e.g., a point that has a thickness of an exact multiple of the contour interval, in this case 50, 60, 70, etc.). From here, aim the contour lines to connect with points of identical thickness, going just to one side or the other of that point if it is not quite identical. In the end all the contours should connect with themselves (no loose ends) or cross the boundaries of the map, and none should cross each other. The only places where loose ends are allowed are where data does not exist. Figure 7.5 shows an example of a typical isopach map.

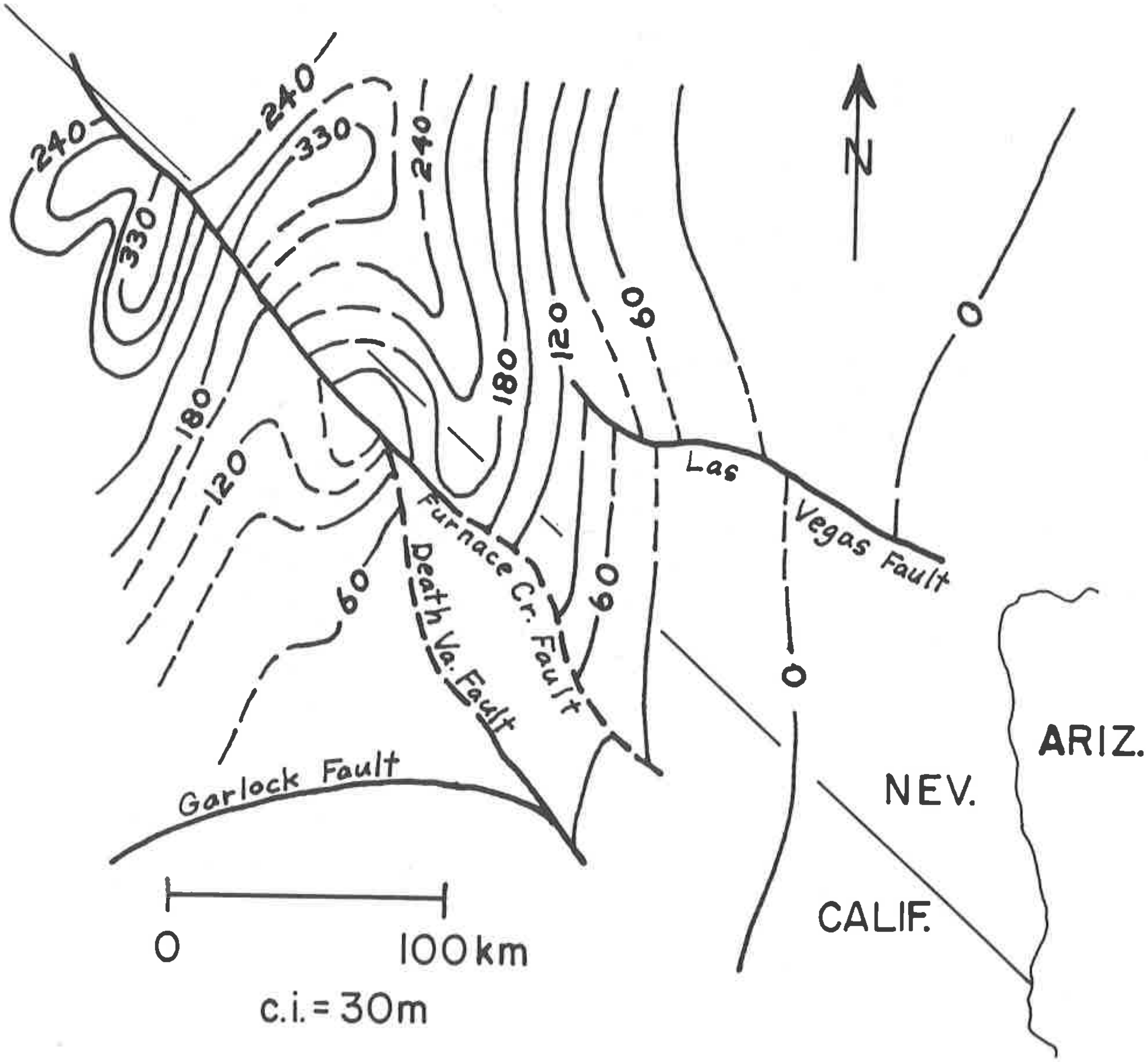

Figure 7.5. Example of an isopach map of the Poleta Formation.

isopach maps. We have not discussed the use of computers here for several reasons. First, There is a danger in relying on the programs without a firm basis in understanding the concepts behind the calculations. This understanding can be best gained, we believe, by first working though the problems, calculations and drafting on your own. Then when you use a computer you will be able to more accurately use the programs, interpret the results and spot trouble areas.

If isopachs seem confusing, just sit down with a topographic map sometime and see how they work. A topographic map is nothing more than an isopach map of the thickness of earth above sea level. Of course they are infinitely more precise due to the capabilities of land-based and aerial survey methods.

A series of paleofacies maps, paleogeographic maps, and isopach maps form a nice summary to any stratigraphic survey. When text is added, these maps can form the core of major geologic reports. The science of interpreting depositional environments will never cease to grow, but the tools outlined in this chapter will always constitute the mode for presenting stratigraphic results to the rest of the scientific community. Probably the major change in the methods presented in this manual is the increasing use of computers to present and compile most of the exercises presented here. Many software packages are available that will quickly and inexpensively plot grain size distributions, draft graphic sections and construct fence diagrams, paleogeographic and

OUTSIDE READING

Blatt and others (1980); Boggs (1986); Davis (1983); Miall (1978); Middleton (1973); Reading (1986); Reineck and Singh (1980); Selley (1985); Walker (1984); Walther (1893-1894); Wilson (1975) isopach maps. We have not discussed the use of computers here for several reasons. First, There is a danger in relying on the programs without a firm basis in understanding the concepts behind the calculations. This understanding can be best gained, we believe, by first working though the problems, calculations and drafting on your own. Then when you use a computer you will be able to more accurately use the programs, interpret the results and spot trouble areas.

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EXERCISES FOR CHAPTER 7

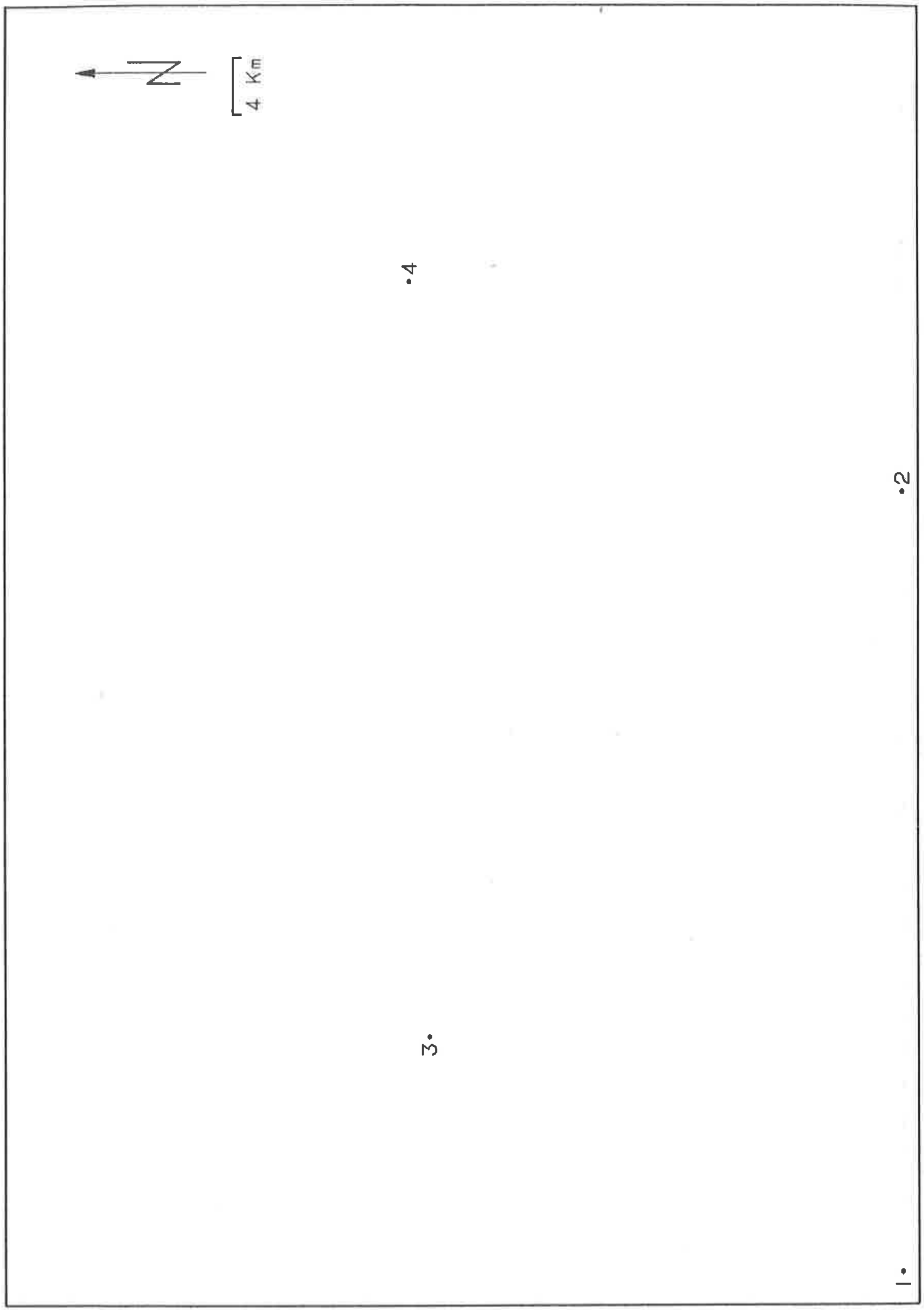
Your fence diagrams constructed in Chapter 6 will serve as the data base for this chapter's set of exercises, refer to your fences in addressing these problems. The exercises comprise three parts: 1) paleofacies/paleogeographic maps; 2) paleogeologic maps; and, 3) isopach maps. We recommend that all of these maps be constructed at the same scale as the fence diagrams on which they are based. Note that base maps are provided for each problem. As you address these reconstructional exercises, it will help to visualize the three-dimensional aspect of the depositional setting, and the distribution of sediment associated with that setting.

Exercise 7.1 - Paleofacies/Paleogeographic Maps

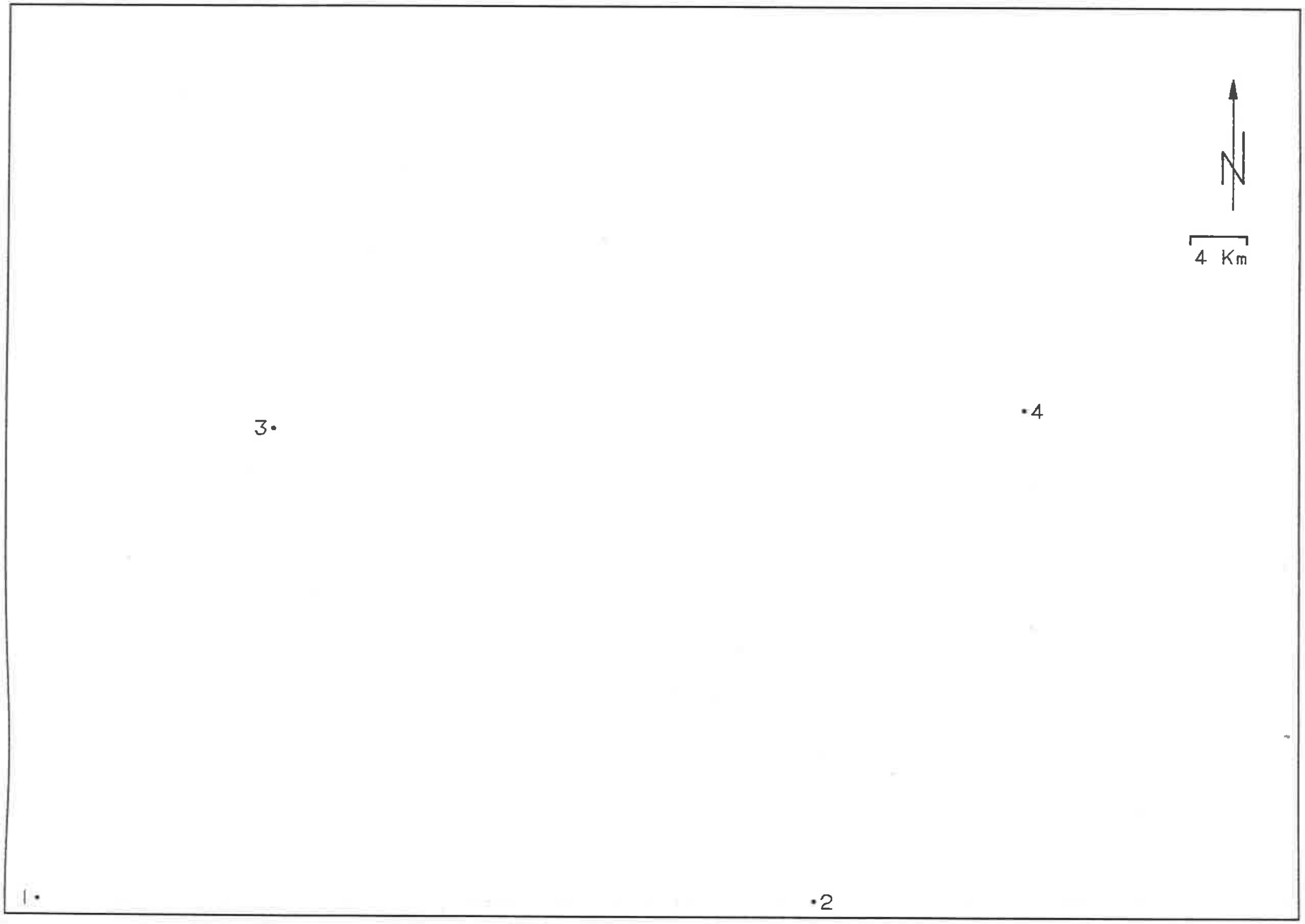
Exercise 7.1.1 Construct two separate paleofacies maps for the volcanic eruptions documented in Exercise 6.3. In comparing these relatively older and younger representations, what important change is recorded in the depositional regime? With regard to glacial stages, what do your maps indicate? Based on the brief rock descriptions and known stratigraphic relations, make your maps also serve as a paleogeographic or paleoenvironmental map by inserting environments of deposition on the same map (e.g., siltstone rhythmites = basinal lacustrine environment).

Exercise 7.1.2. Construct paleofacies/paleogeographic maps for both biostratigraphic horizons, A and B, from Exercise 6.5. What major change in depositional regime do these horizons document? What process likely caused the change?

Exercise 7.1.3. Construct a paleofacies/paleogeographic map at the biostratigraphic horizon in Exercise 6.4.

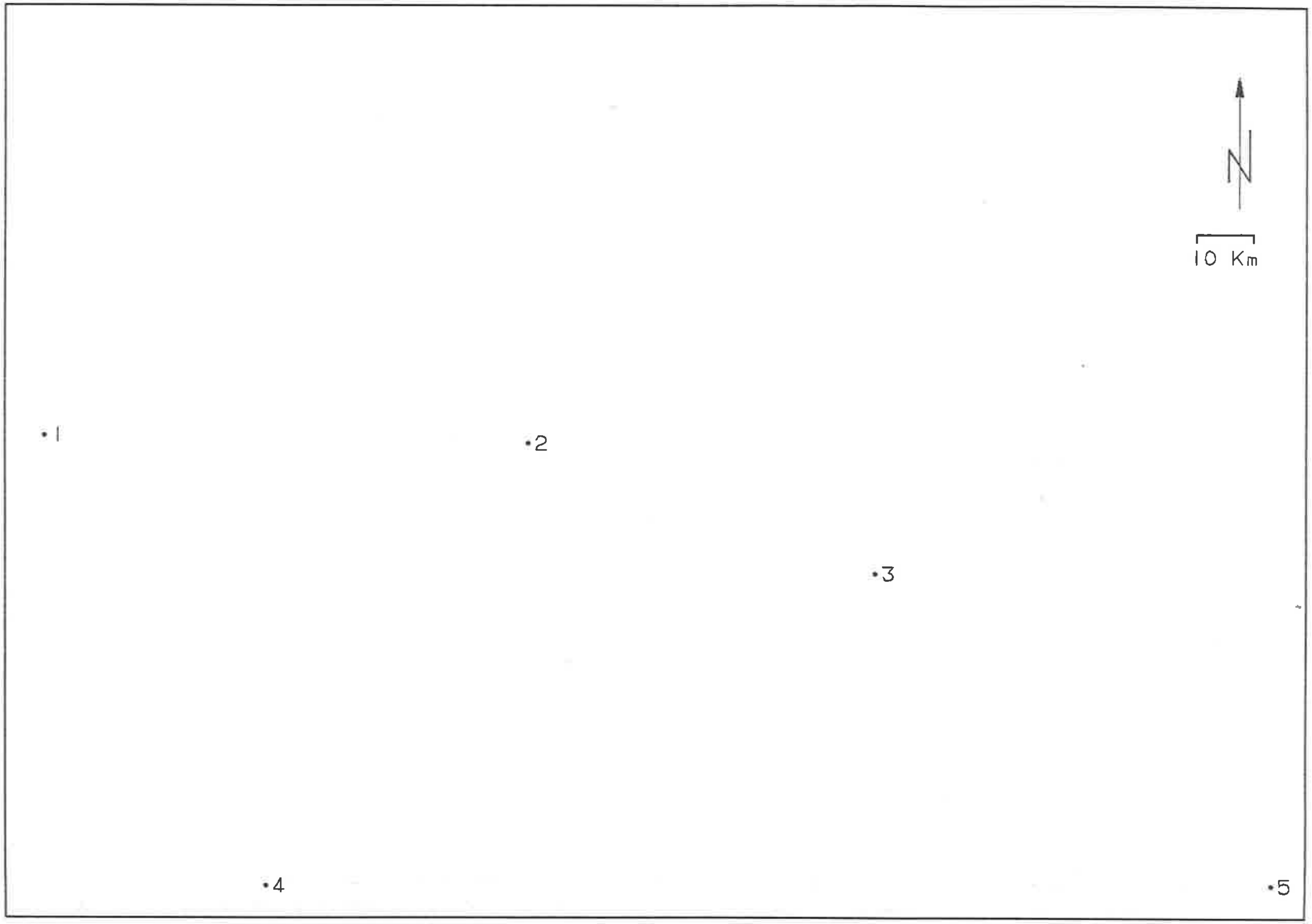


Exercise 7.1.1 - A PALEOFACIES/PALEOGEOGRAPHIC MAP, at the older volcanic event, Exercise 6.3.

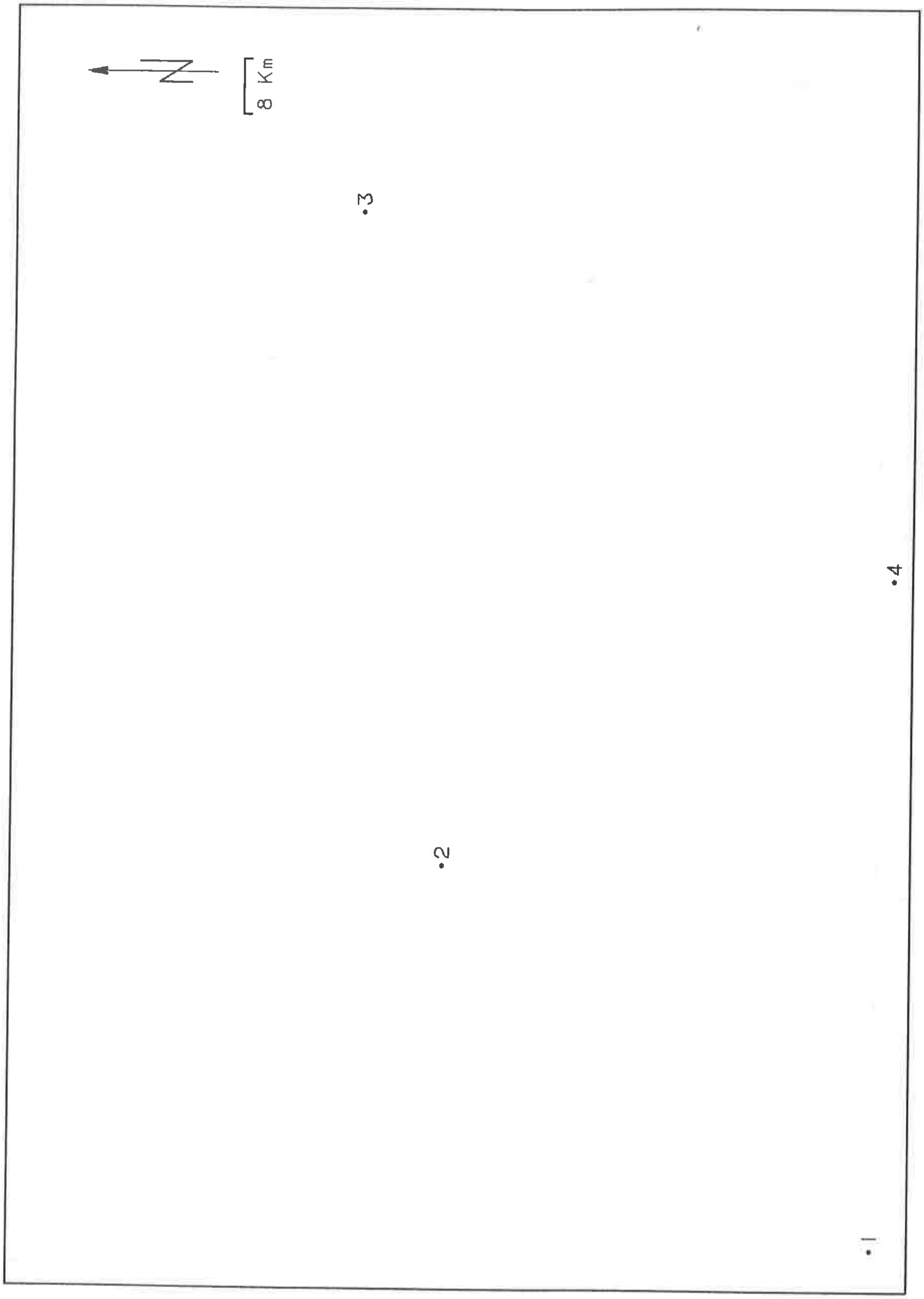


Exercise 7.1.1 - B PALEOFACIES/PALEOGEOGRAPHIC MAP, at the younger volcanic event, Exercise 6.3.

Exercise 7.1.2 - A PALEOFACIES/PALEOGEOGRAPHIC MAP, at the base of assemblage zone B, Exercise 6.5.



Exercise 7.1.2 - B PALEOFACIES/PALEOGEOGRAPHIC MAP, at the base of assemblage zone A, Exercise 6.5.



Exercise 7.2 - Paleogeologic Maps

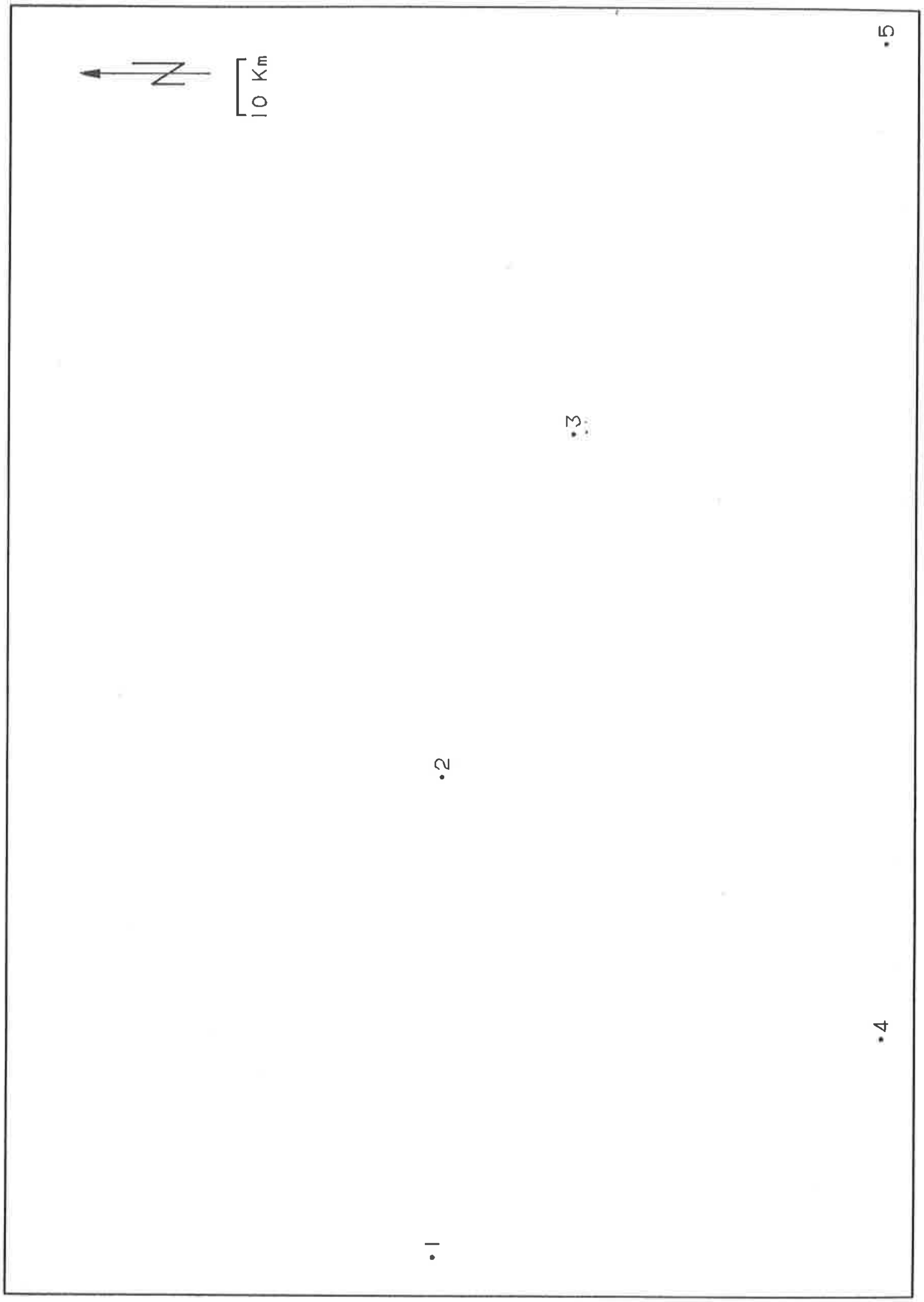
Construct separate paleogeologic maps at the following horizons:

Exercise 7.2.1. Below the youngest (uppermost) unconformity in Exercise 6.5.

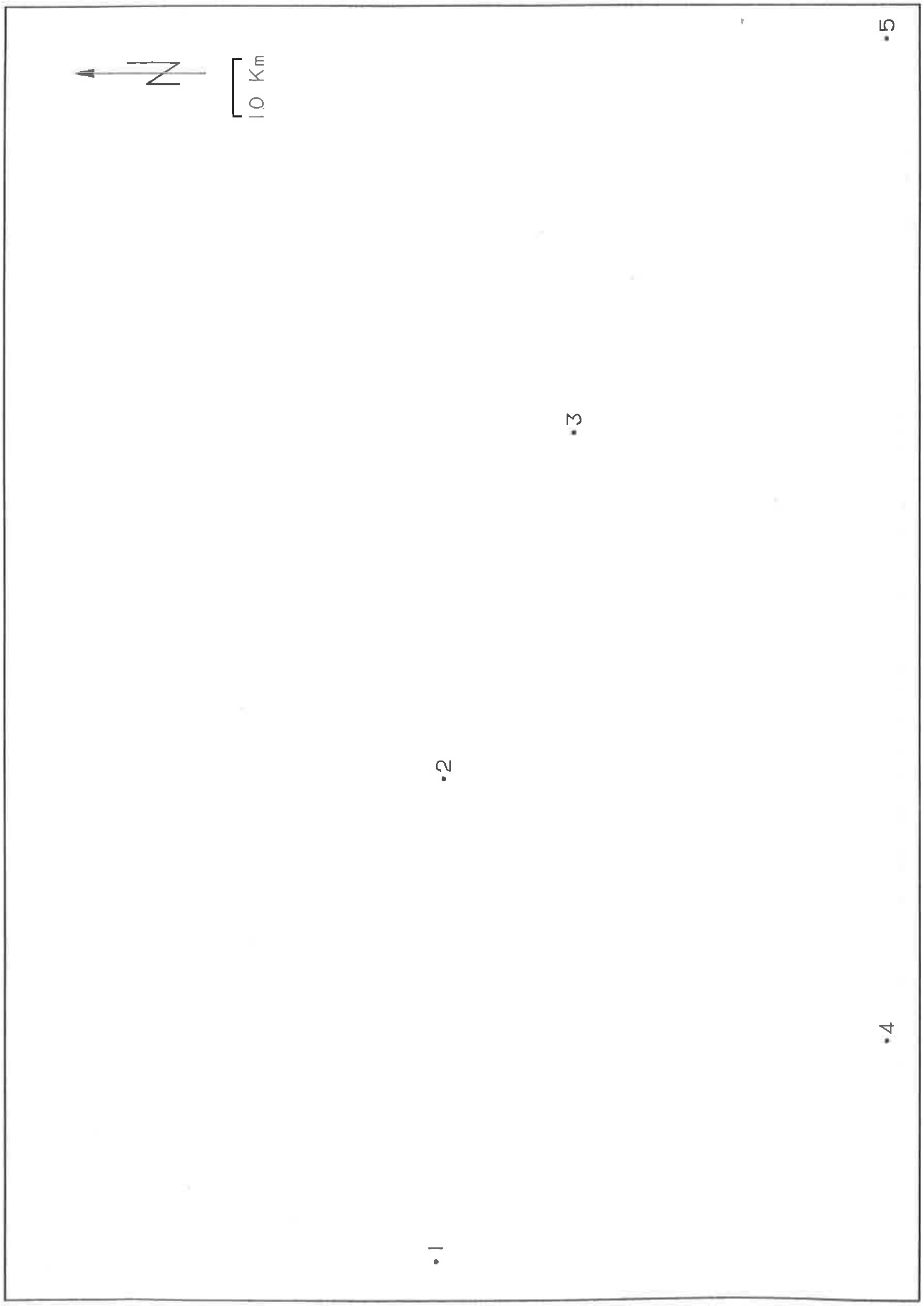
Exercise 7.2.2. At the oldest volcanic event in Exercise 6.3.

Exercise 7.2.3. At the biostratigraphic horizon, B, in Exercise 6.5.

Exercise 7.2.4. Below the youngest unconformity in Exercise 6.2.

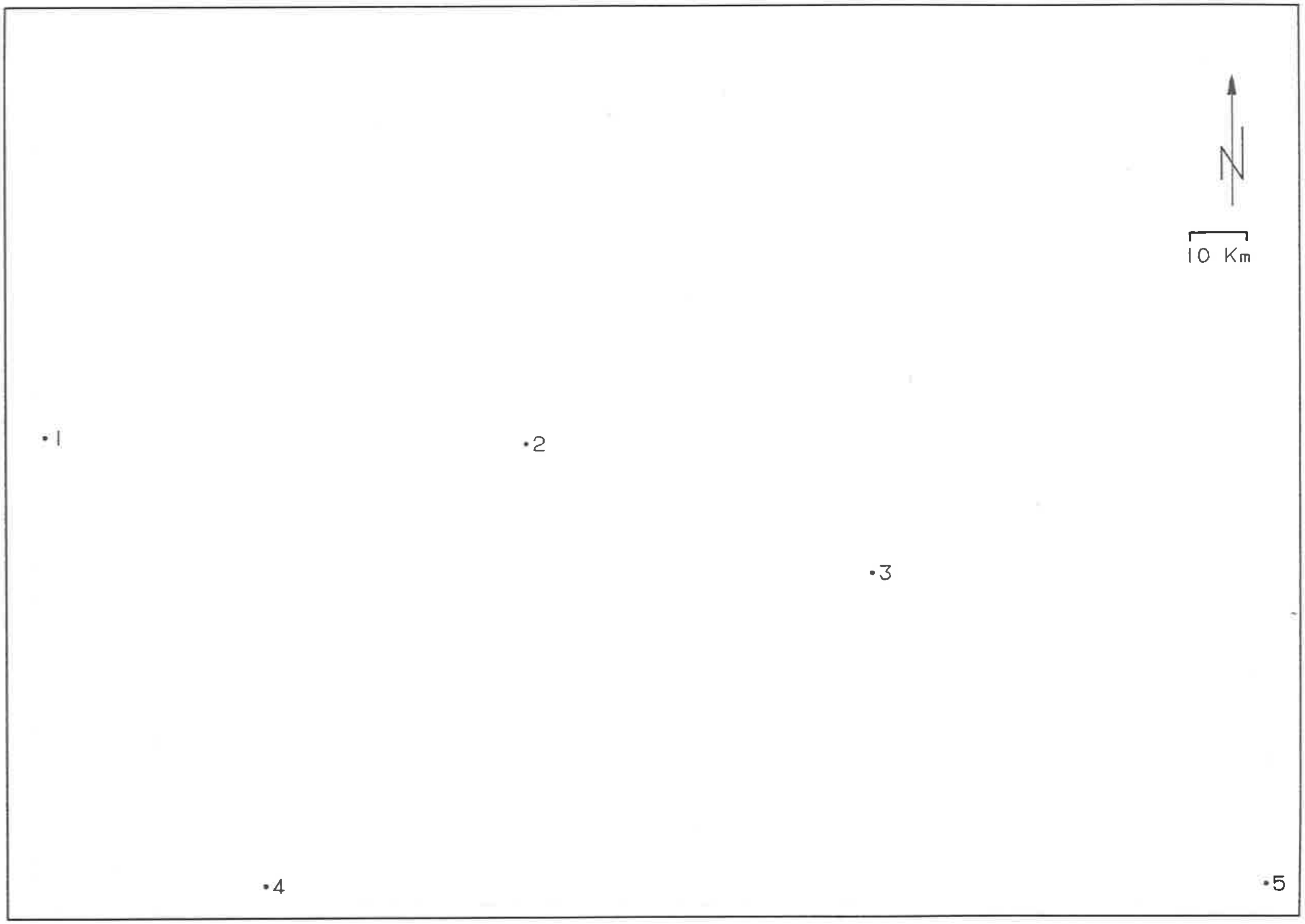


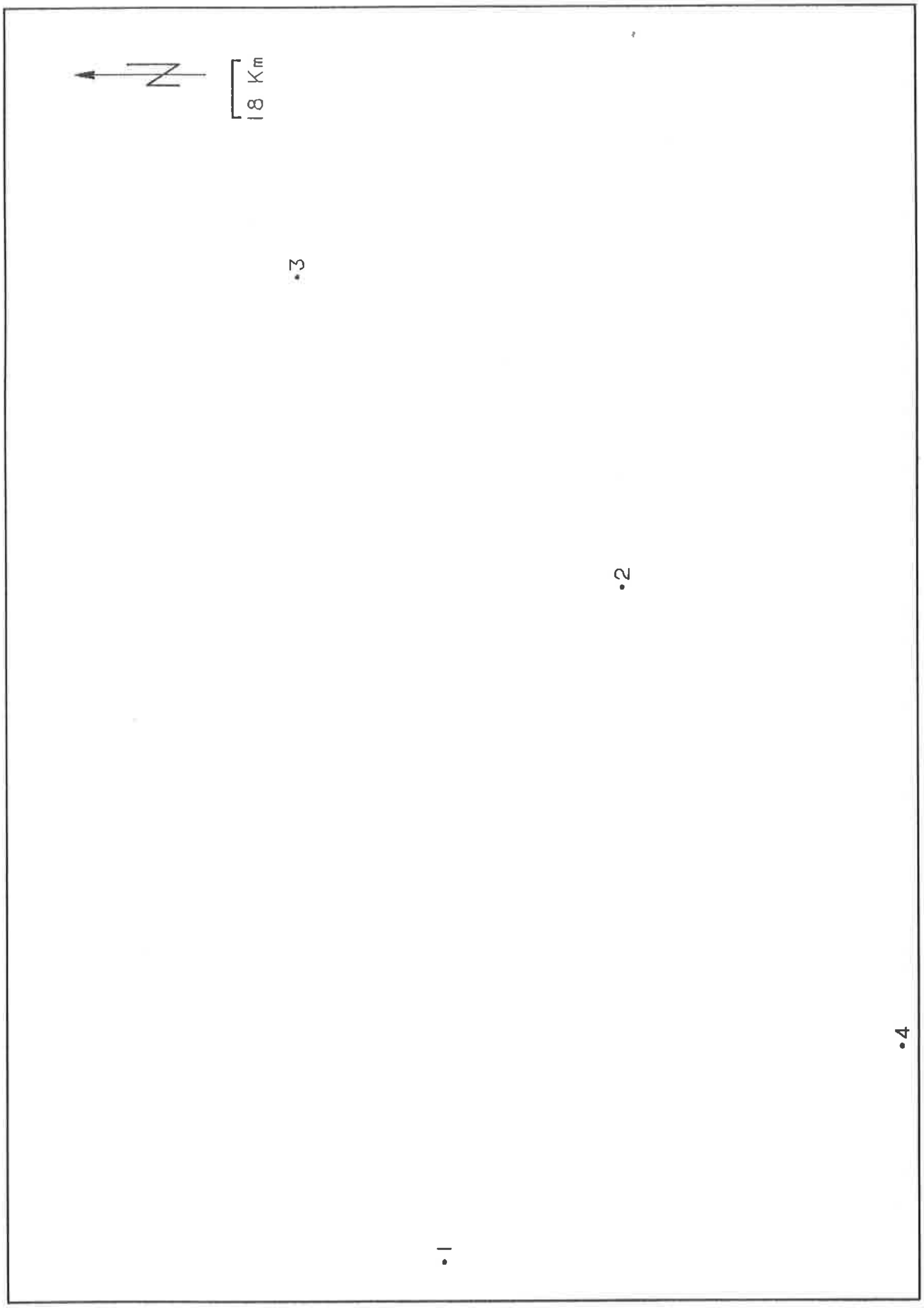
Exercise 7.2.1 PALEOGEOLOGIC MAP, below the youngest unconformity, Exercise 6.5.



Exercise 7.2.2 **PALEOGEOLOGIC MAP, at the oldest volcanic event, Exercise 6.3.**

Exercise 7.2.3 PALEOGEOLOGIC MAP, at the base of assemblage zone B, Exercise 6.5.





Exercise 7.2.4 PALEOGEOLOGIC MAP, below the oldest unconformity, Exercise 6.2.

Exercise 7.3 - Isopach Maps

Using data from your measured sections (Exercises in Chapter 6), and the supplemental data given below, construct isopach maps for the following units. The additional data, here given, identifies the locality and the unit thickness (e.g., 5/10.1m indicates the unit of interest at locality 5 is 10.1 meters thick). Use the contour interval (CI) given for each problem. Remember to keep in mind the 3-dimensional picture you might envision or expect of each depositional setting, especially when contouring areas where limited data exists.

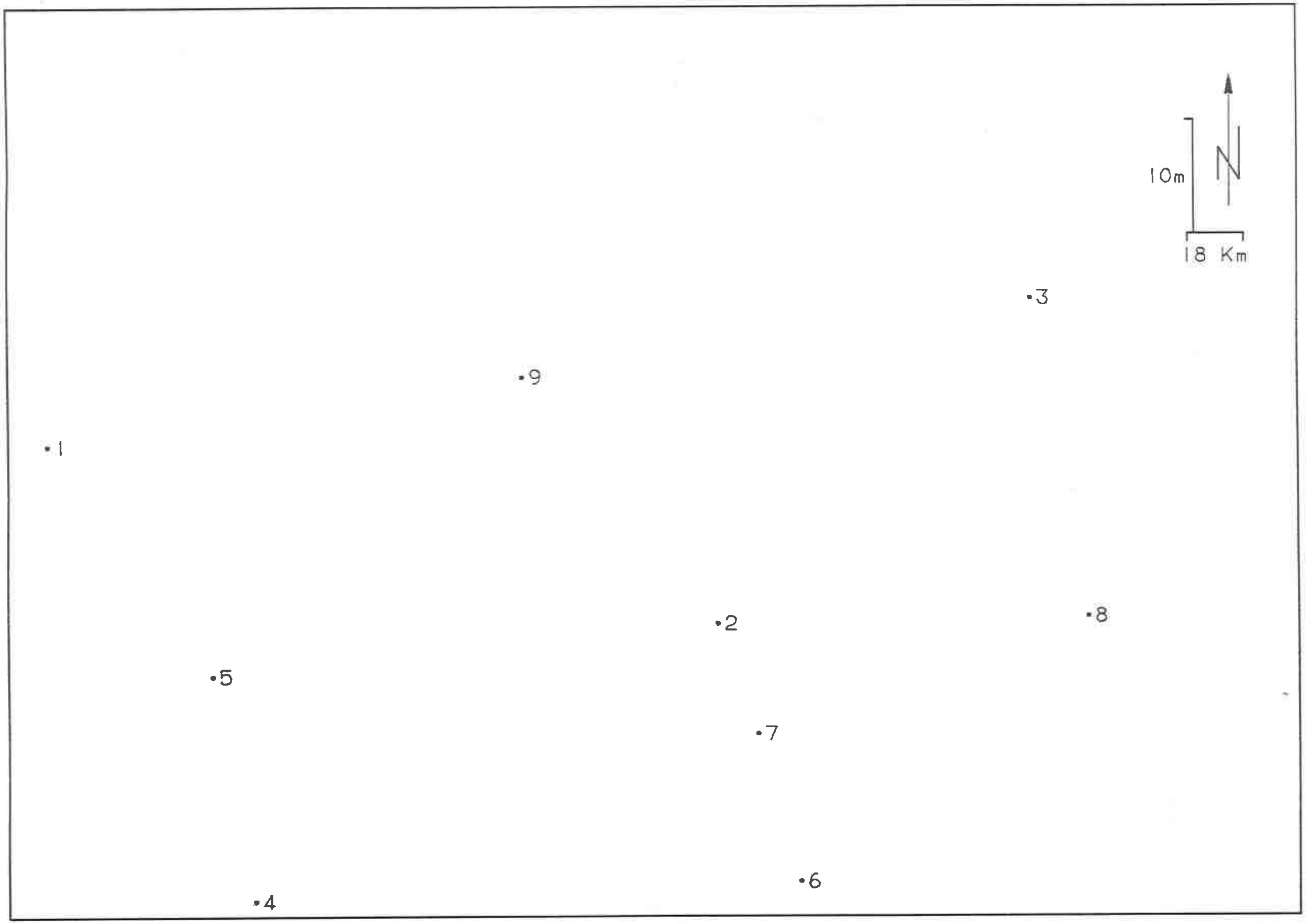
Exercise 7.3.1. The eolian sands below the oldest unconformity, Exercise 6.2. Additional data: 5/3m, 6/4m, 7/7m, 8/3m, and9/6m. CI = 1 meter.

Exercise 7.3.2. The lowest dolomite in Exercise 6.5. Additional data: 6/6.3m, 7/5.5m, 8/3m, 9/1.5m, and 10/1.2m. CI = 1 meter

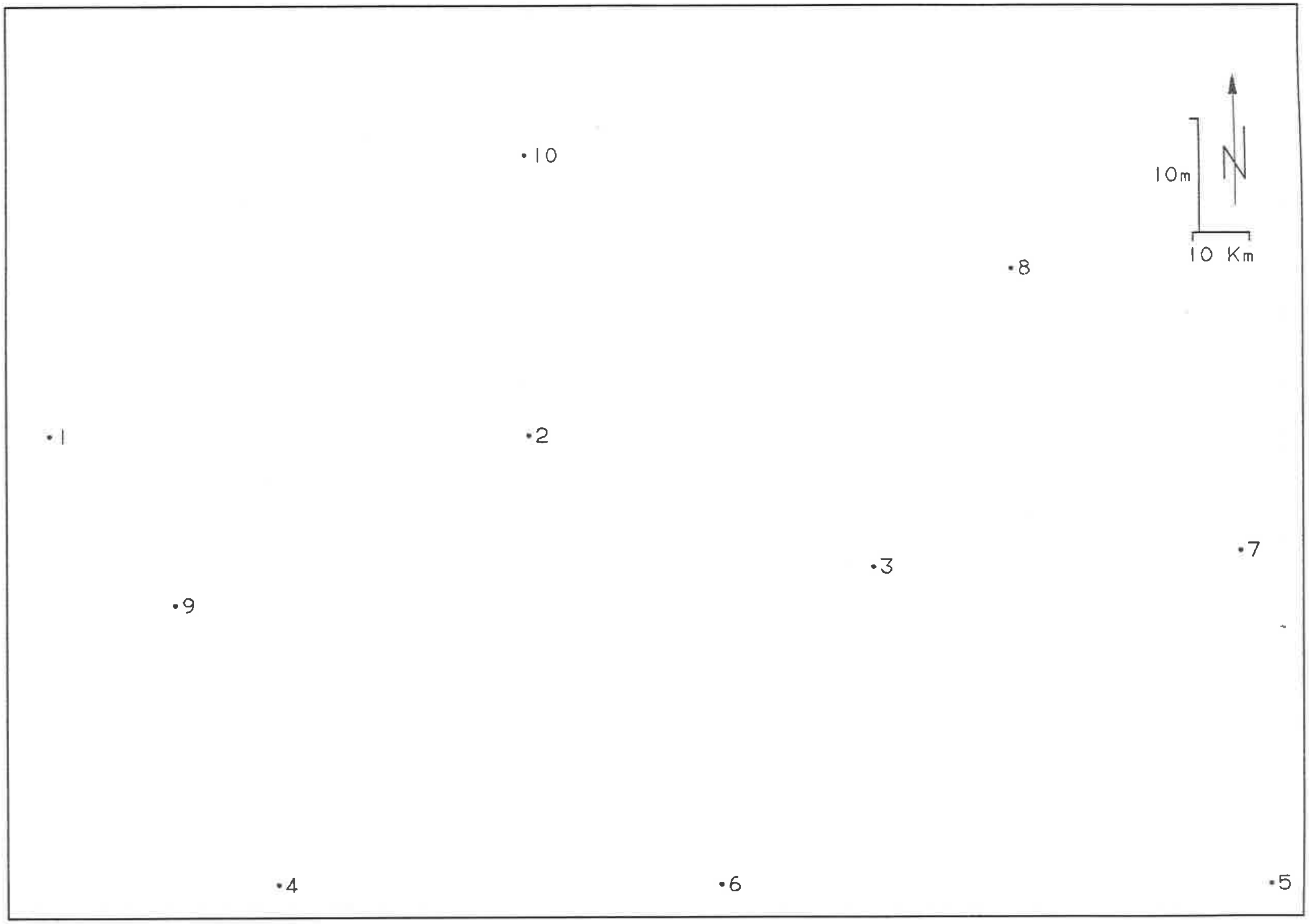
Exercise 7.3.3. The lowest diamictite in Exercise 6.3. Additional data: 5/16m, 6/10.4m, 7/6m, 8/9.5m, 9/10m, 10/1m, 11/5m, 12/12m, and 13/6.5m. CI = 2meters.

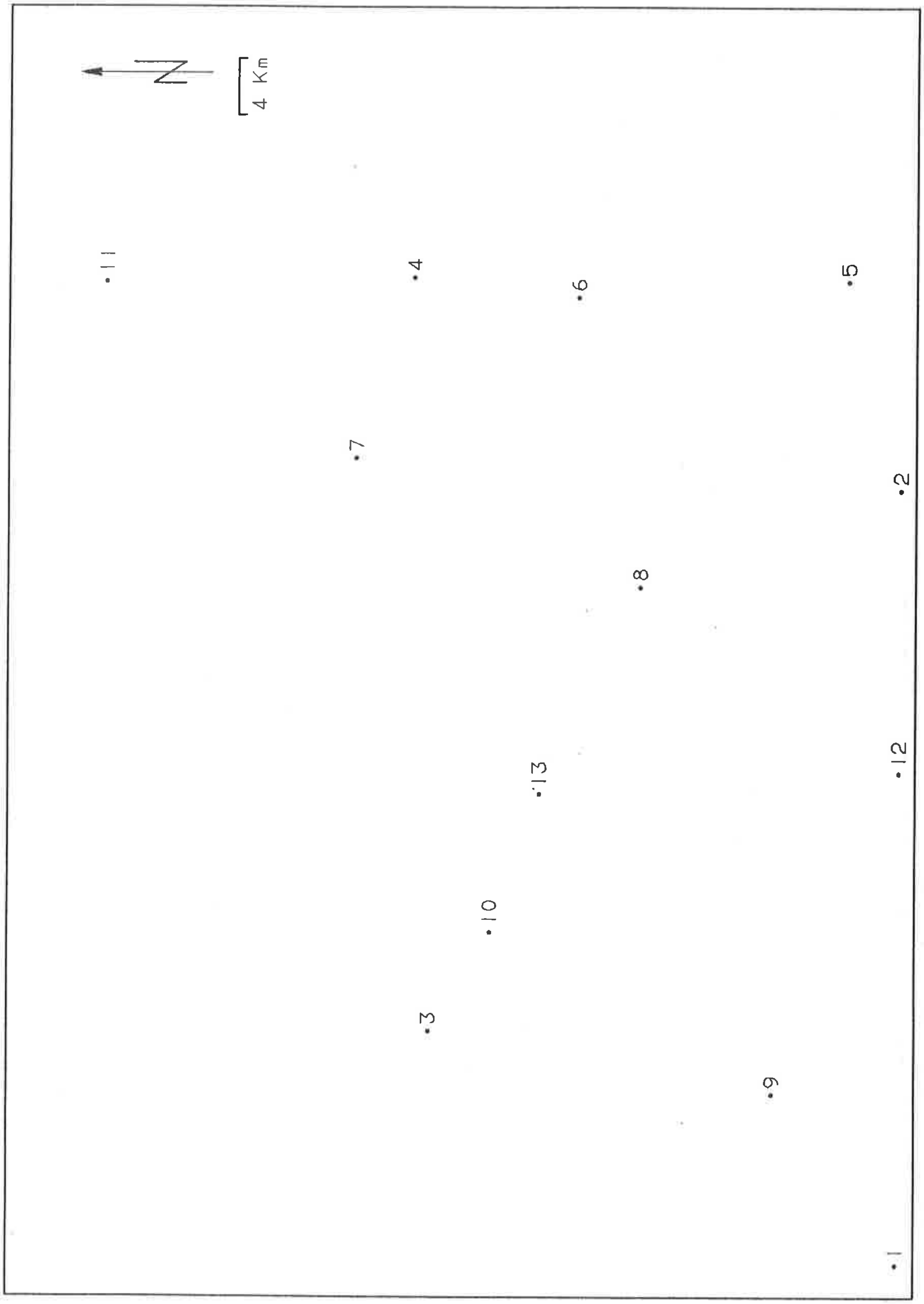
Exercise 7.3.4. The lower siltstone rhythmite unit from Exercise6.3. Additional data: 5/30m, 6/22m, 7/9m, 8/25m, 9/31m, and 10/24m. CI = 4meters.

Exercise 7.3.1 ISOPACH MAP, eolian sands below the oldest unconformity, Exercise 6.2.

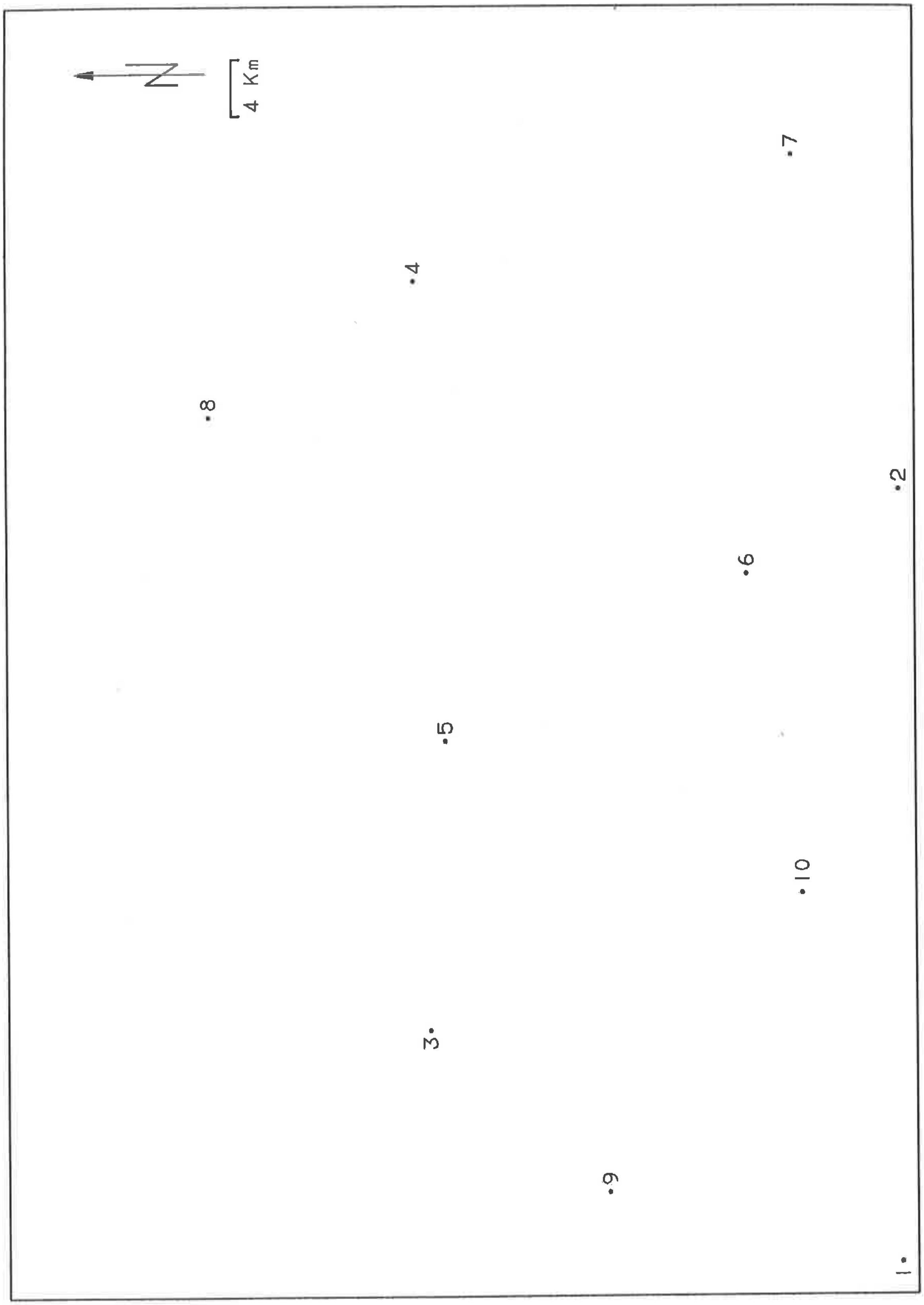


Exercise 7.3.2 ISOPACH MAP, the lowest dolomite, Exercise 6.5.





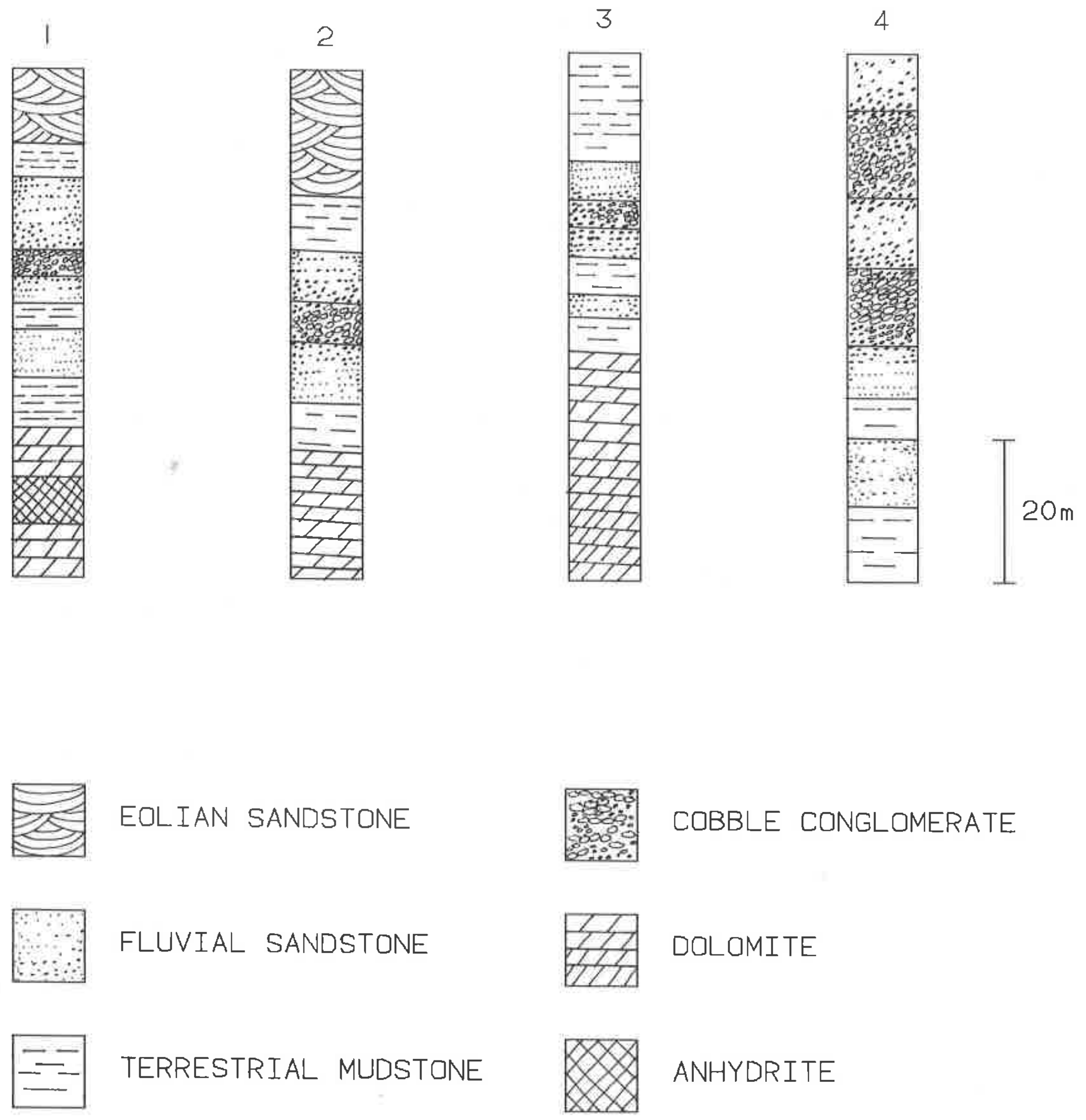
Exercise 7.3.3 ISOPACH MAP, the lowest diamictite, Exercise 6.2.



Exercise 7.3.4 ISOPACH MAP, the lower siltstone rhythmite unit, Exercise 6.3.

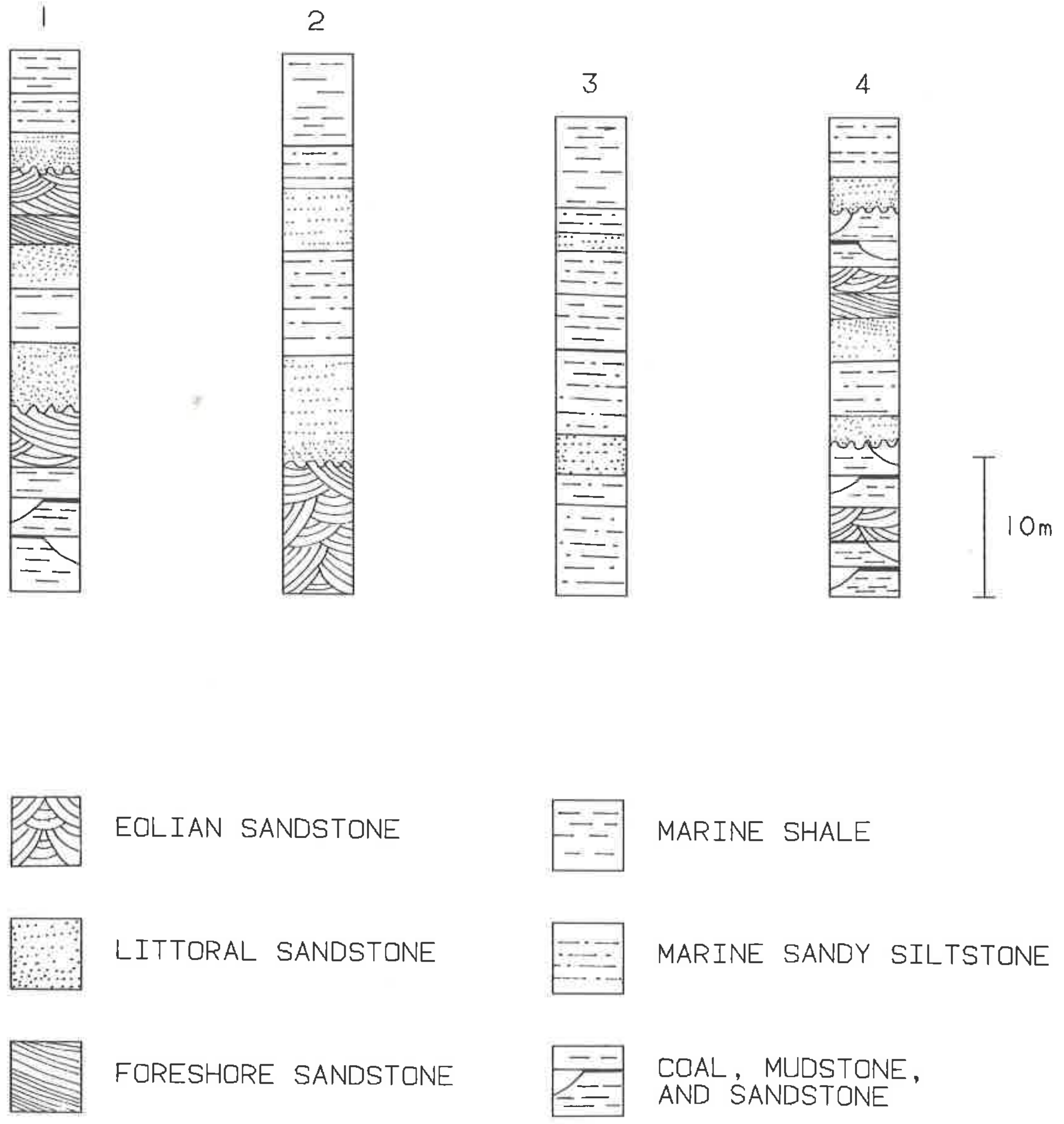
Exercise 6.1

Construct a fence diagram from the following columns. Does your three-dimensional correlation allow you to more accurately locate the source of coarse clastic sediment than did your two-dimensional correlation from Chapter 2 (Exercise 2.2)? What apparent direction is this source material derived from? Where is the playa located in this "basin"? Where were the dunes forming with respect to the other depositional environments?



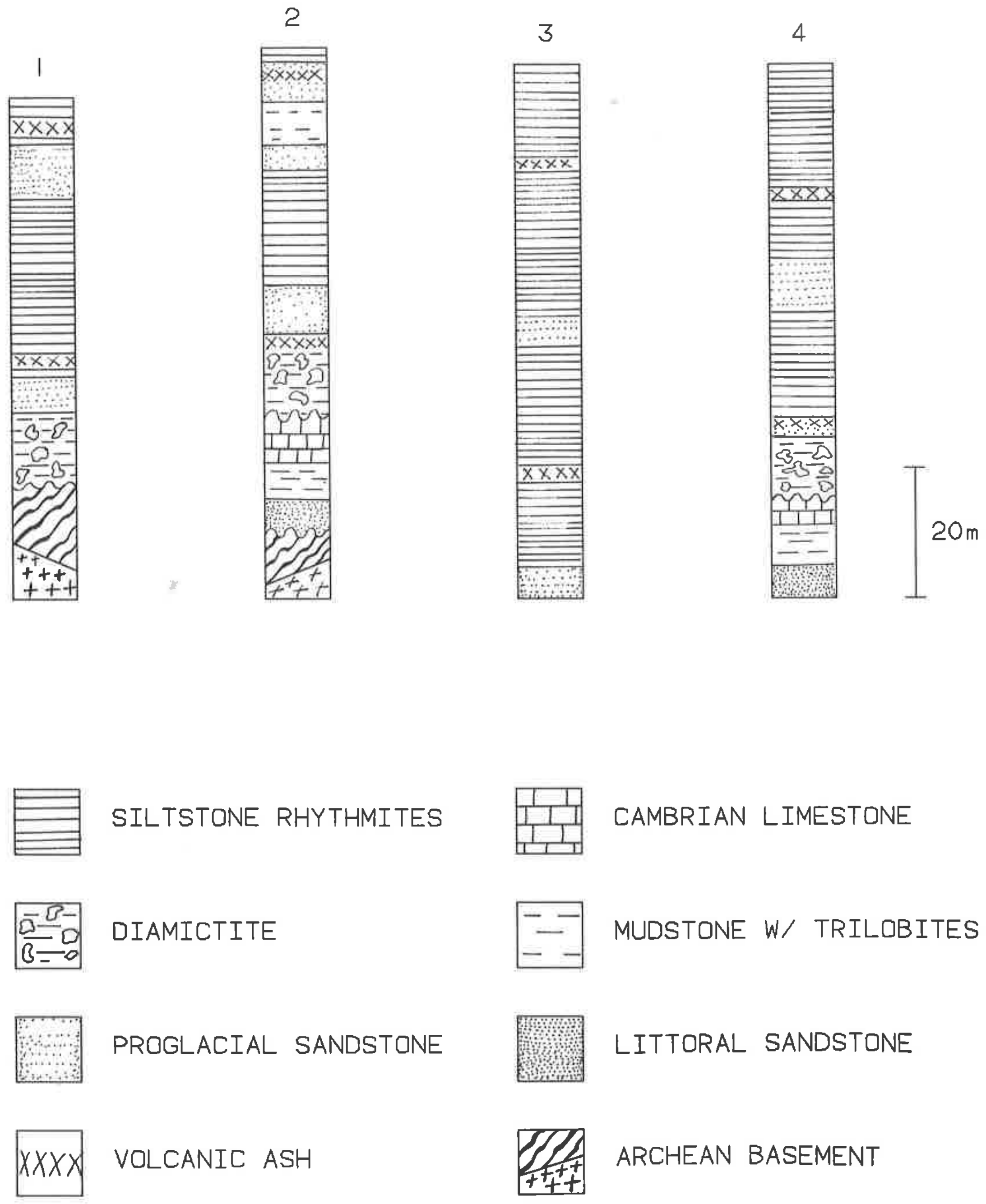
Exercise 6.2

Give an approximate orientation for the barrier islands responsible for deposition of part of this sequence? Which direction is offshore? Onshore? Why are there no unconformities present at locality #3? Which locality best illustrates a classical coastal progradational sequence? After recognizing the locality, where in the sedimentary section does it occur?



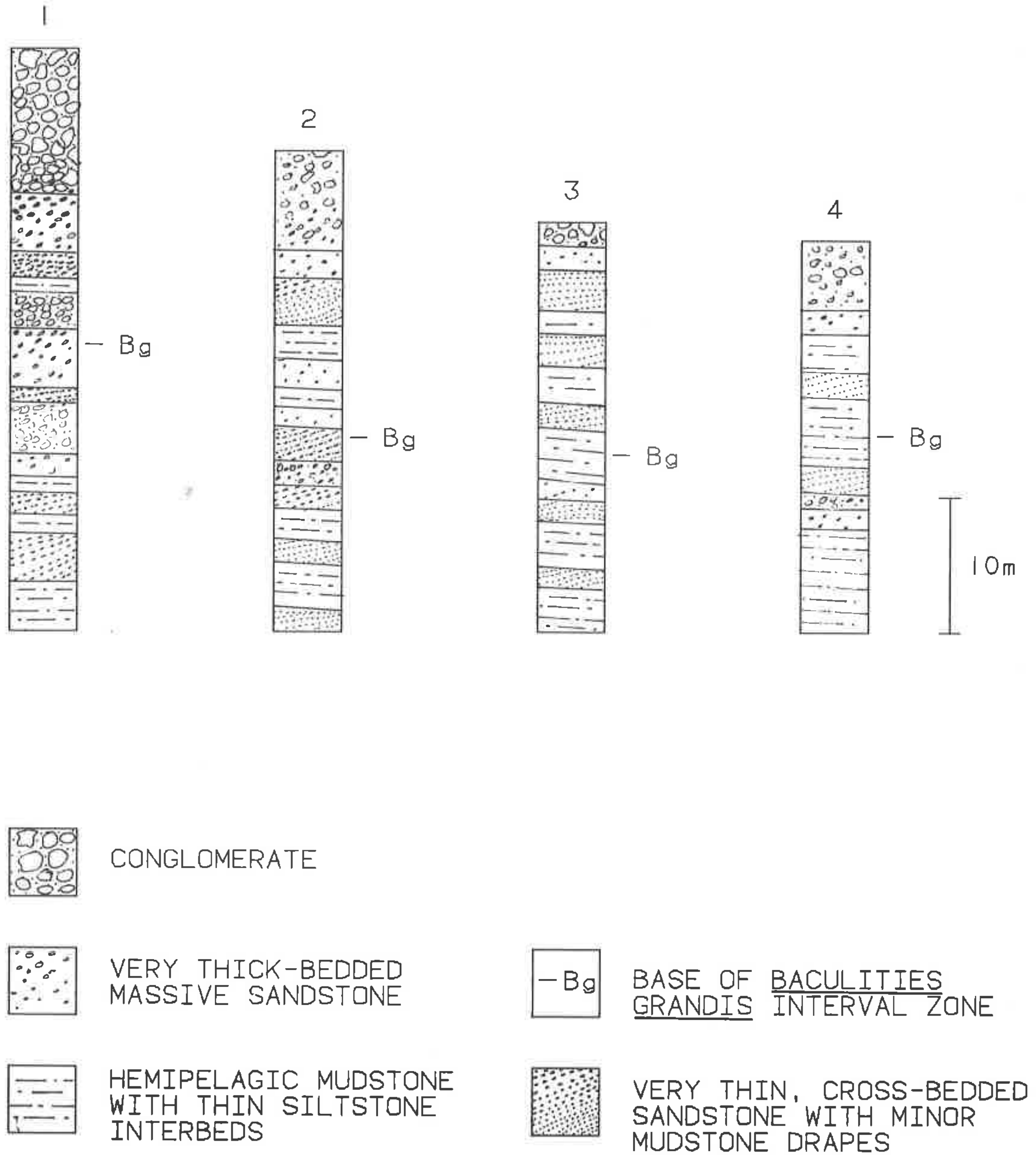
Exercise 6.3

Would growth and retreat of ice lobes more likely be recorded in Section 2 or Section 4? Would rises and falls in the lake level more likely be recorded in Section 3 or Section 4? Explain.



Exercise 6.4

Identify the proximal and distal portions of this "basin". Given your understanding of the depositional setting represented, what sedimentation process, active in this setting, may account for the contemporaneous deposition of different rock types at different localities?



Exercise 6.5

Do Sections 1, 2, 3, and 5 appear to lie across or parallel to the depositional strike? What depositional environment did the dolomites form within? Why do you think no fossils were found to identify the base of the Assemblage zone at locality #5? Hint, think about your chronostratigraphic correlation.