Exercise: belemnite stretch at Morcles Nappe

Reading: Fundamentals of Structural Geology, Ch 5
Hossain, K. M., 1979, Determination of strain from stretched belemnites. Tectonophysics, v. 60, p. 279-288.

Figure 1 is a drawing by H. Badoux of boudins composed of deformed belemnite guards from the Liassic slate of the Morcles Nappe at Leytron, Valais, Switzerland. Figure 5.2 from the textbook shows a down-plunge section of the folds in the western Helvetic nappes including Morcles Nappe. Outcrop and scenic photographs in this area are found on the website for chapter 5.

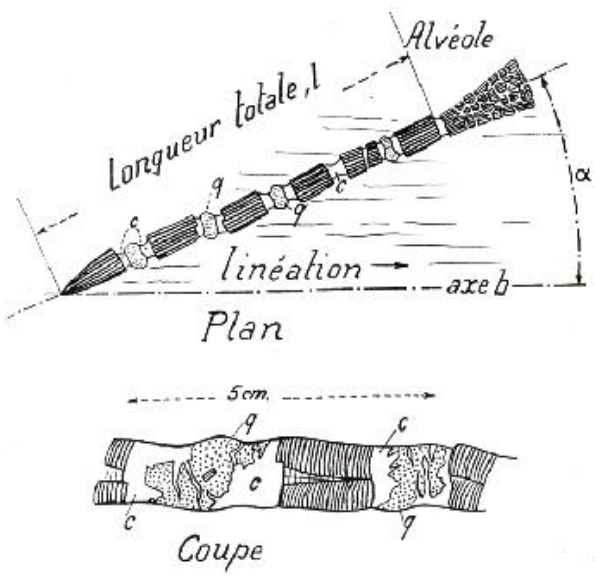

Figure 1. Broken and extended fossil belemnite with quartz, *q*, and calcite, *c*, filling. Reprinted from (Badoux, 1963) with permission of l'Université de Lausanne.

The belemnites at Leytron were measured by Hossain (1979) in order to calculate principal stretches. The belemnites are generally cylindrical with a circular rostrum, and the cavities created by fragmentation are filled with quartz and calcite.

The length after deformation was measured as the total length of the belemnite guards plus the quartz plus the calcite. The initial length was assumed to be the sum of the lengths of the belemnite fragments, so these fragments were assumed to be rigid when the surrounding rock deformed. The *gross stretch* of each belemnite, S_i, is the ratio of final length to initial length.

Hossain measured the orientation of the stretched belemnites with respect to a stretching lineation in the plane of the slaty cleavage. This lineation was assumed to be parallel to the direction of maximum stretch, S_1. The stretching lineation is composed of small

elongate ridges or groves visible on broken slabs of the slate. For each belemnite there is a measurement of the angle, a_i, between the presumed direction of the maximum stretch and the direction of the stretch along the belemnite. Hossain measured n = 196 belemnites with various orientations relative to the stretching lineation in the slate.

The problem is to determine the maximum, S_1, and minimum, S_2, stretches in the plane of the measurements, that is the plane of the slaty cleavage. The relationship between the principal stretches and the stretch of a particular material line, S_i, oriented at angle, α_i, is:

$$\left(\frac{\cos\alpha_i}{S_1}\right)^2 + \left(\frac{\sin\alpha_i}{S_2}\right)^2 = \left(\frac{1}{S_i}\right)^2, \quad i = 1, n \tag{1}$$

In order to compute S_1 and S_2, measurements of S_i and α_i for stretched belemnites with two or more distinct orientations are used to solve n versions of (1) simultaneously. Hossain (1979) found a "best fit" to the large and scattered data set, assuming that all the data represent a single state of strain. In other words it was assumed the strain was homogeneous across the outcrops that yielded the measurements.

1) Rearrange (1) into the form of a straight line:

$$y_i = mx_i + b \tag{2}$$

2) The data were extracted by digitizing Figure 5 of Hossain (1979) and are given in belemnite.txt as two columns in the format:

$$\begin{matrix} x_1 & y_1 \\ x_2 & y_2 \\ \vdots & \vdots \\ x_n & y_n \end{matrix} \tag{3}$$

Read the data and recreate Hossain's Figure 5 using MATLAB.

3) Calculate the best fitting straight line to the belemnite data set. Write down the parameters of this line and compute the principal stretch magnitudes. Hossain estimated that S_1 = 2.7 and S_2 = 1.35. How do your results compare to his? Describe this deformation.

4) Use your estimates of the principal stretches to compute the ratio of the final area to initial area in the plane of the slaty cleavage. What can you say about the third principal stretch in terms of its magnitude and direction?

5) Assume that volume was approximately unaltered by the deformation and that two of the principal stretches were in the plane of the measurements. Calculate the stretch S_3

normal to the plane of measurements and describe this component of the deformation. How might this relate to the slaty cleavage that defines the plane of the measurements?

6) Evaluate the assumption that the deformation in the vicinity of a deformed belemnite is homogeneous. Use the outcrop photograph from Hossain (1992) and the sketch (Figure 1) to support your evaluation.

7) Briefly describe the design of either a laboratory or a numerical experiment to determine the principal stretches from "model" belemnites under conditions of heterogeneous deformation.

