FRY3D: a new educational open-source computer tutorial designed for the collection, manipulation, and visualization of three-dimensional strain data at the undergraduate level

Jeffrey R. Webber & **Keith A. Klepeis** Department of Geology, The University of Vermont, Burlington, VT 05405 U.S.A. *jrwebber@uvm.edu Keith.Klepeis@uvm.edu*

1. Abstract

The evaluation and quantification of deformation in 3-D is an essential aspect of structural geology. However, this component of geology is commonly difficult to teach at the undergraduate level due to problems associated with the manipulation and visualization of 3-D data. In order to help alleviate limitations associated with this style of analysis, we present the script FRY3D written within the open source environment R. This script allows the user to construct 2-D Fry plots from sectional images of a deformed conglomerate model and graphically determine each sectional strain ratio. The script combines these analyses into a single interactive 3-D Fry plot that the user can directly navigate in real time. From this synthesis, the magnitude and orientation of principle strain axes are obtained using the readily accessible program Ellipsoid 2003. A second script processes the results of this program and produces an array of plots designed to aid visualization; including a stereographic projection, a Nadai graph, and an interactive three-dimensional strain ellipsoid model. In order to evaluate the effectiveness of this tutorial in helping undergraduate students understand 3-D data, a two part assessment of 3-D concepts was administered to a structural geology class of 20 people. The first part was conducted after a sectional Fry analysis, and the second was completed after the FRY3D tutorial. Student responses were divided into three groups based on the overall level of strain comprehension. Our results indicate a significant decrease in the total number of student misconceptions after the script presentation. Due to the functionality provided by FRY3D to rapidly manipulate data and visualize 3-D strain, we assert that the augmentation of this tutorial to traditional structural geology curricula significantly reduces misconceptions of deformation associated with a single 2-D analysis, and also may provide a valuable tool for research training.

2. General considerations

Motivation: the ability to determine gradients in the shape, distortion, and orientation of rock fabrics within terrains dominated by ductile deformation can provide key information pertaining to the style of deformation and regional scale kinematics.

Problem: in order to document these regional fabric gradients, analytical strain techniques must be applied to three-mutually perpendicular sections and synthesized into a single fabric ellipsoid. Although two-dimensional strain calculation methods are commonly taught in structural geology courses, three-dimensional strain analyses are typically avoided due to time constraints and difficulties in visualization presentation.

In this study: We present an open-source tutorial to teach three-dimensional strain following the Fry method. This tutorial allows students to manipulate two-dimensional data and better visualize the construction of a strain ellipsoid from these data.

3. Synthetic data generation

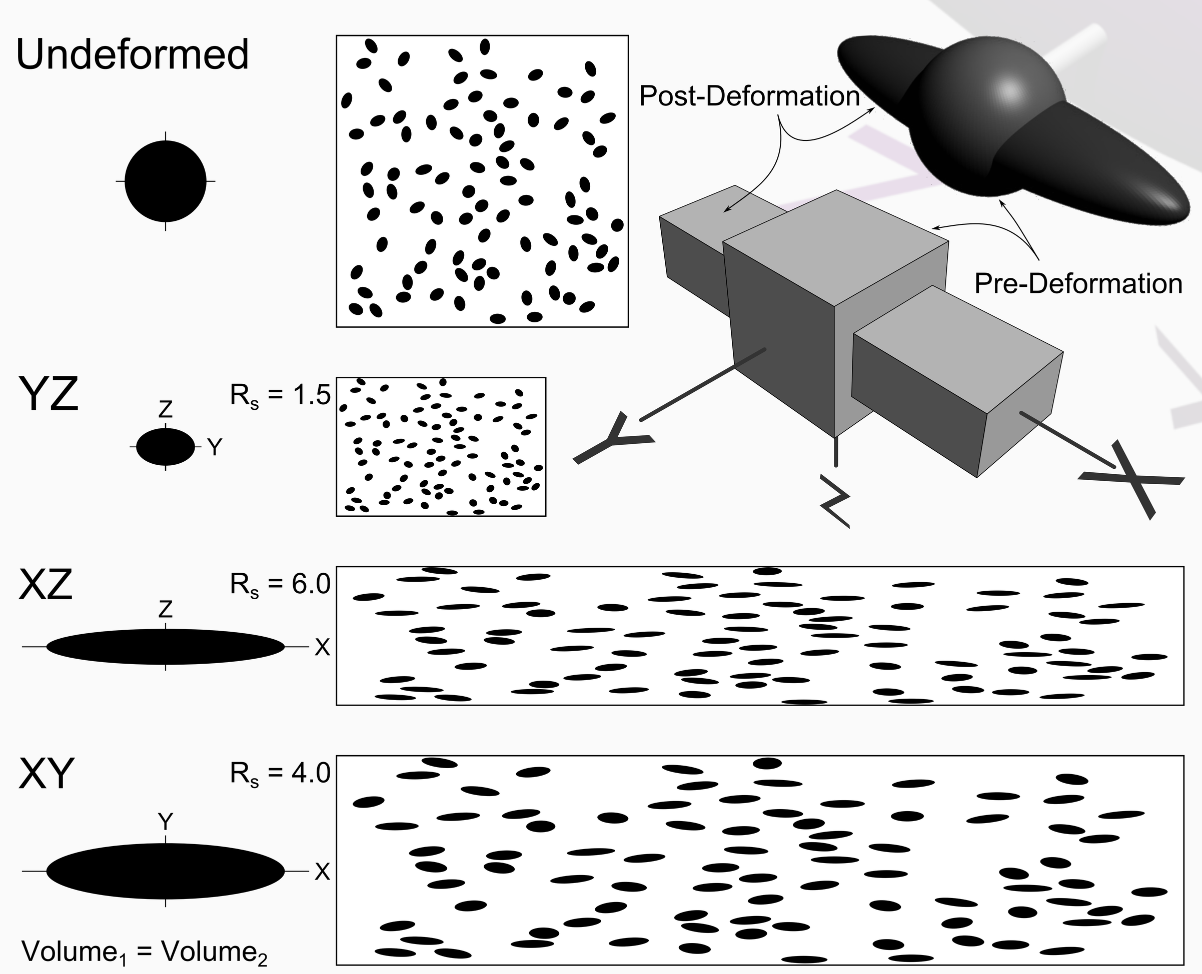

Figure 1. Finite homogeneous deformation applied to a volume of originally ellipsoidal objects displaying a uniform orientation. Undeformed state is represented by a circle for any given section through the volume. Following the conservation of volume through deformation, the shapes of object traces, the object centroid locations, and the degree of semi-major axis alignment will reflect the two-dimensional state of strain for a given section. These are represented by ellipses. The synthesis of ellipses in three-dimensions construct to produce a strain ellipsoid that represents the three-dimensional state of strain. The use of this synthetic dataset allows the user to directly compare their calculations to the expected.

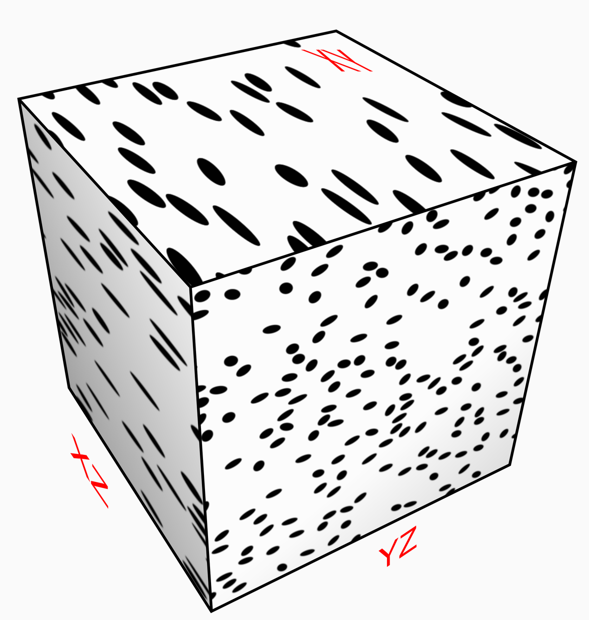

Figure 2. Illustration displaying the synthetic deformed conglomerate used in this tutorial. Each face of the cube below corresponds to one of the three principle planes of strain that are deformed based on a known three dimensional state of strain. The model can be physically constructed and oriented in the classroom to help students relate the analyses to the data. The benefit of a synthetic data set for teaching is the ability to compare calculations to a known value.

4. FRY3D user operation and methodology applied to synthetic data

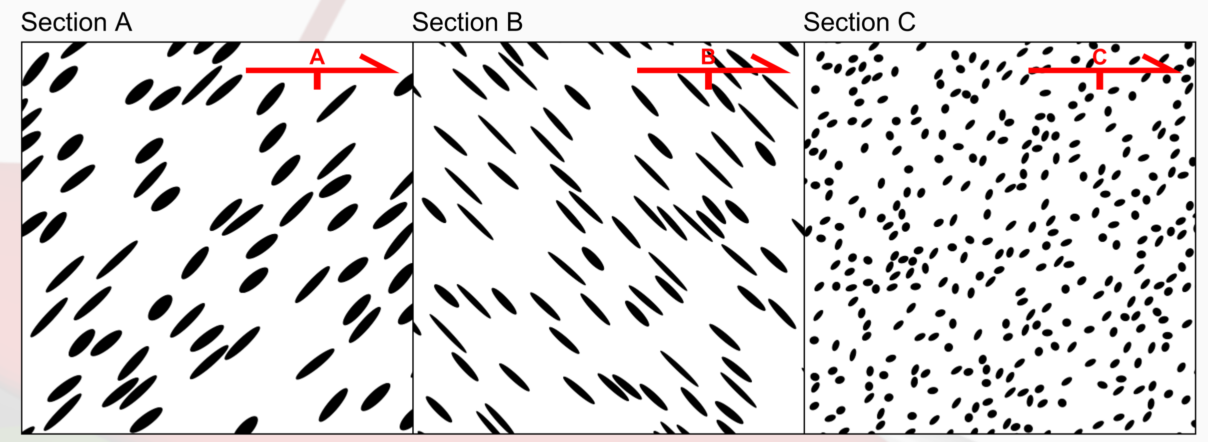

Figure 3. Sectional data ready for analysis. Each of the three faces are mutually perpendicular and are oriented so that their top edge is aligned parallel to the line of strike with the direction of strike (following right-hand-rule) is to the right. Each section is tagged with orientation information so that the two-dimensional analysis can be placed into a three-dimensional context. FRY3D (Webber, 2012) allows the user to interactively select the centroids of each object.

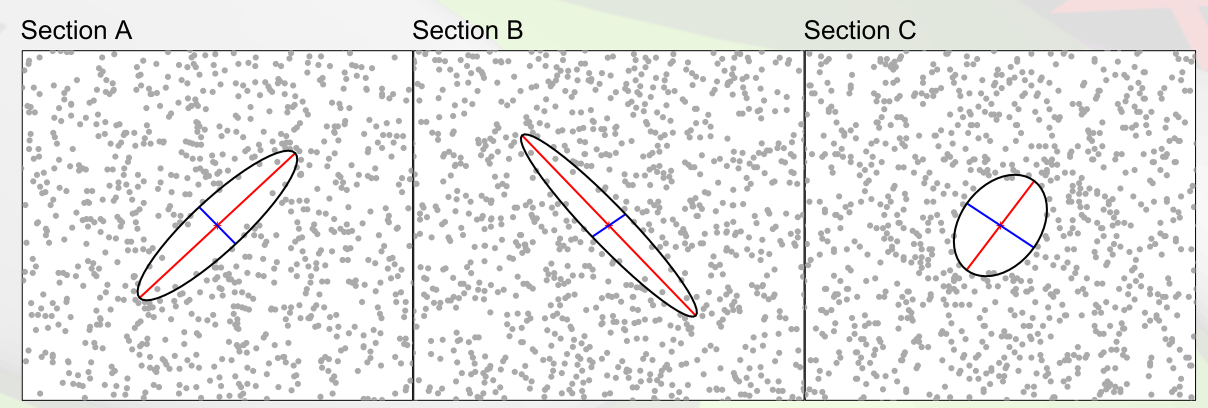

Figure 4. Based on the coordinates of each object centroid as selected by the user, FRY3D automatically generates a two-dimensional Fry plot (Fry, 1979). In each fry plot, the user is prompted to select the central void apogee and perigee, from which an ellipse is constructed.

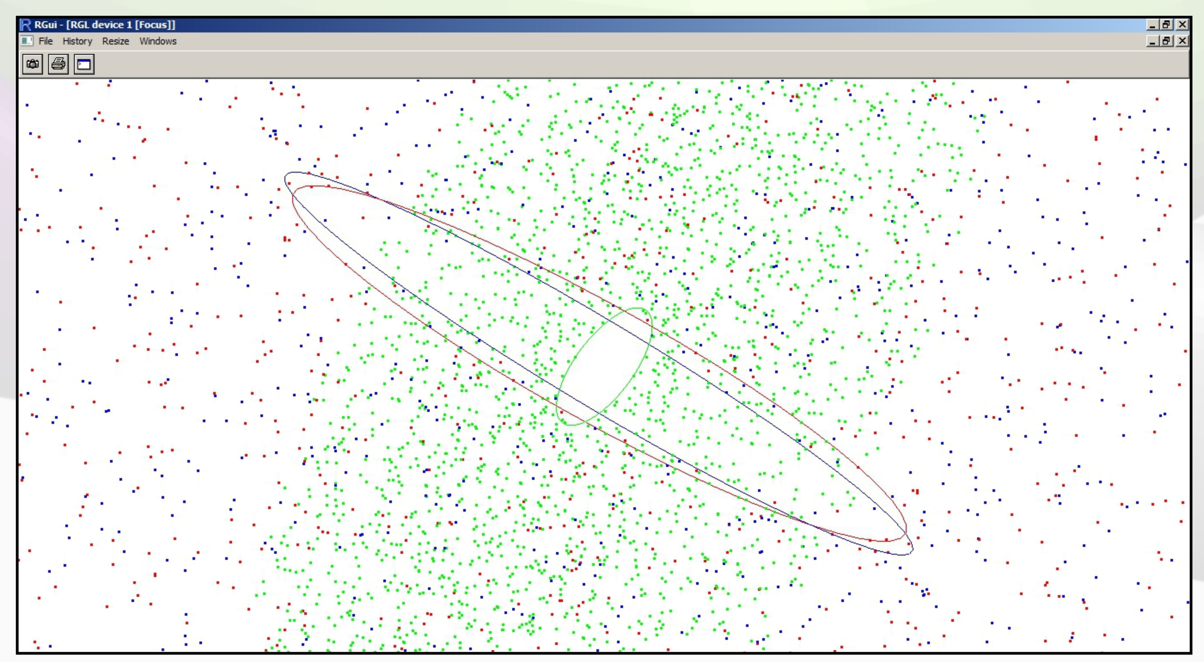

Figure 5. The two-dimensional Fry plots are rotated and compiled within an interactive real time three-dimensional viewer. Raw data are color-coded based on the sectional analysis and are contained within a geographic reference frame. A side effect of this routine produces a file directly compatible with the program Ellipsoid 2003 (Launeau and Robin, 2005) that statistically fits an ellipsoid to the sectional data.

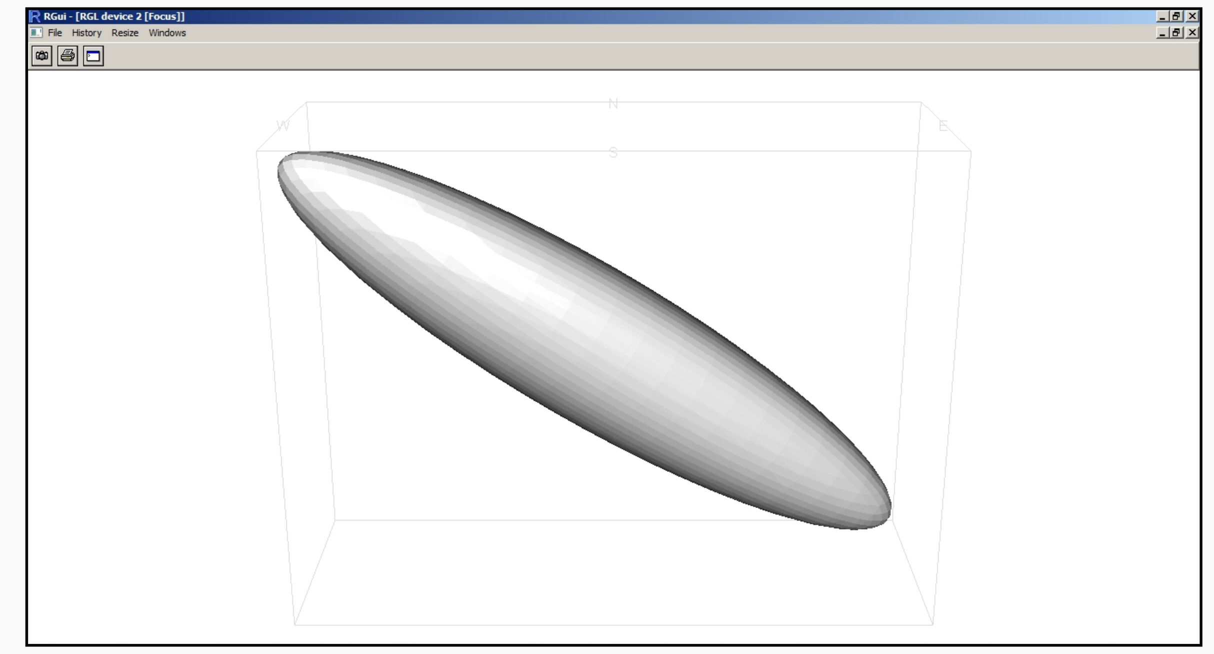

Figure 6. After running Ellipsoid 2003 on the generated file to produce a statistically fitted strain ellipsoid, the results are imported into the tutorial and an array of visualization aids are produced. The window capture image in this figure displays an interactive model of the fitted ellipsoid correctly oriented within a geographic reference frame that can be directly compared to the three-dimensional Fry plot.

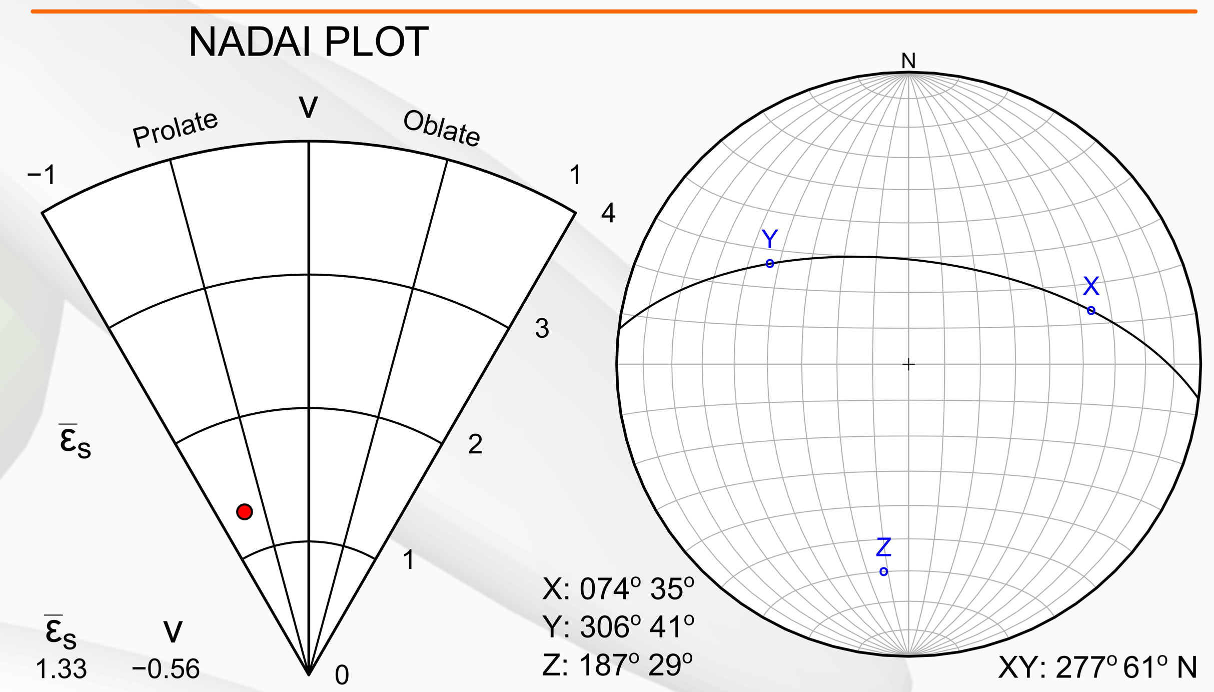

Figure 7. FRY3D also generates a Nadai plot and a stereographic project. The Nadai plot allows the user to graphically relate the magnitude of distortion (octahedral shear strain) to the strain symmetry (Lode parameter) within strain magnitude space. The stereographic projection, based on functions provided in the RFOC package (Lees, 2011), contains the principle axes of the triaxial ellipsoid and the XY principle plane of strain.

5. Natural example

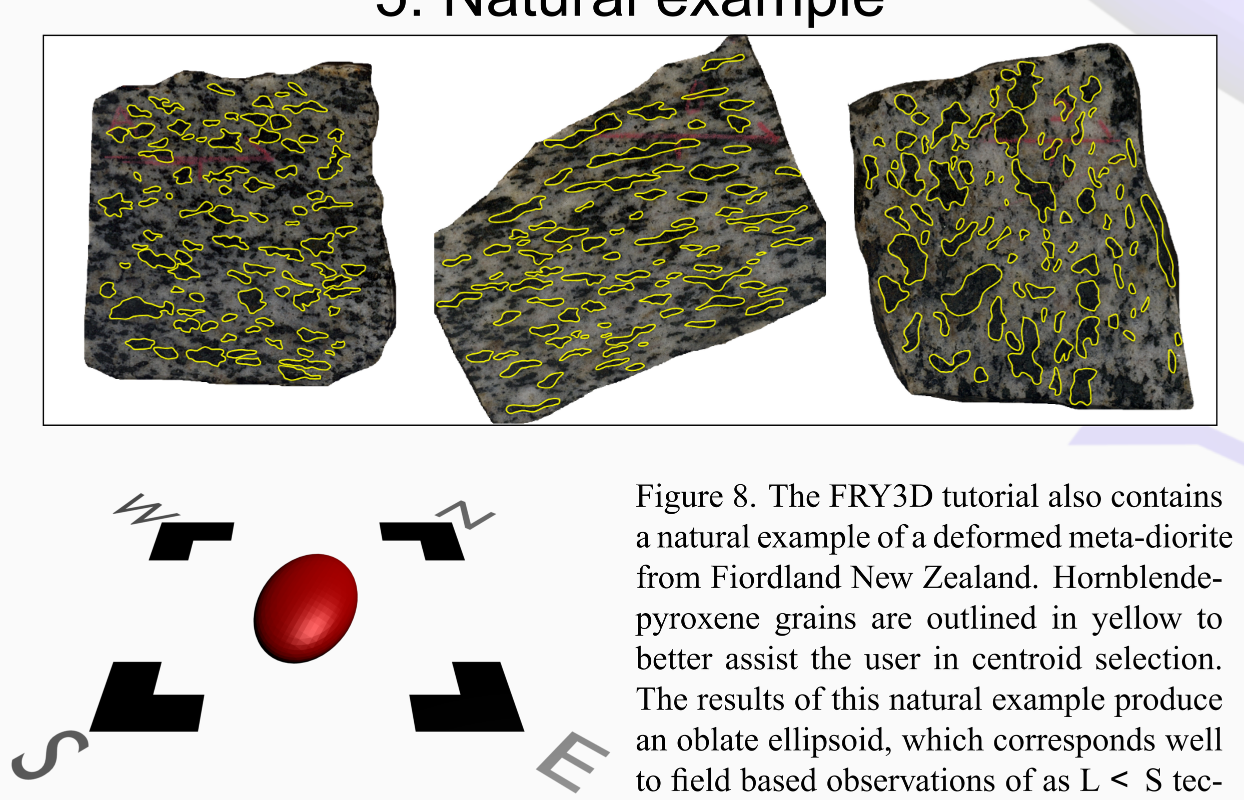

Figure 8. The FRY3D tutorial also contains a natural example of a deformed meta-diorite from Fiordland New Zealand. Hornblende-pyroxene grains are outlined in yellow to better assist the user in centroid selection. The results of this natural example produce an oblate ellipsoid, which corresponds well to field based observations of as L < S tectonite.

6. Effectiveness evaluation

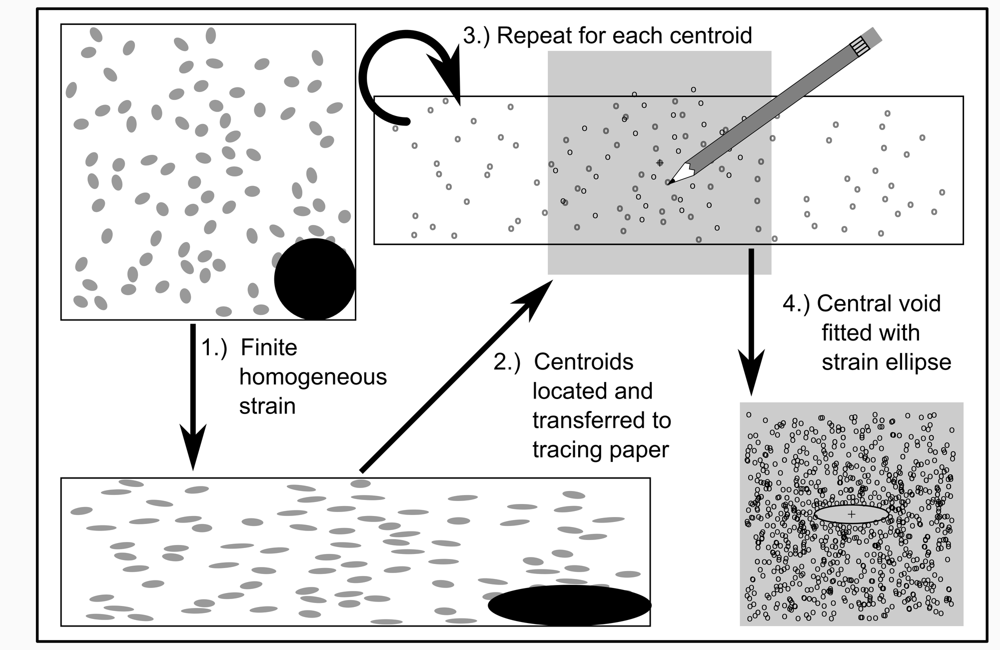

Figure 9. In order to semi-quantitatively evaluate the utility of this tutorial a two part questionnaire was given to a structural geology class of twenty undergraduates. Prior to the evaluation, students manually completed one two-dimensional Fry analysis of a deformed ooid-bearing limestone. Students were the asked how this analysis defines the state of finite strain in three-dimensions. Following the FRY3D tutorial, the students were asked a similar question. The results are presented in figure 10.

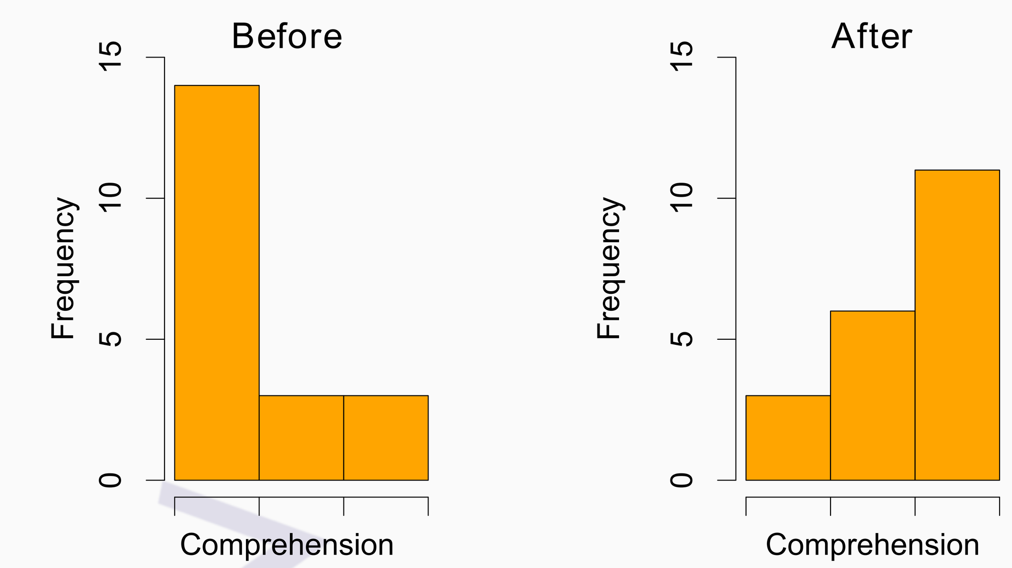

Figure 10. Students answered the following questions: "What does this 2D representation of strain inform us about deformation in three-dimensions?" and "Why must the state of strain be represented by an ellipsoid and not an ellipse?" before and after the tutorial, respectively. Responses to these questions were grouped into three categories corresponding to either: 1.) lacks substantial understanding; 2.) some concepts developed but lack a comprehensive understanding; and 3.) exhibits a comprehensive understanding of the nature of deformation in three-dimensions. The two histograms in this figure document the categorized responses with increasing comprehension in bins from left to right. These results generally indicate a higher level of class understanding after the FRY3D tutorial.

7. Conclusions

- The characterization of fabric gradients in deformed terrains can provide important information concerning the nature of rock flow and regional kinematics.
- Logistical impediments to the teaching of strain calculation in three-dimensions can be reduced through the application of FRY3D in the class room setting by: allowing for the rapid processing of two-dimensional sectional data, the visualization of sectional analyses in a three-dimensional context, and the ability to characterize the properties of a fitted strain ellipsoid in terms of shape, distortion, and orientation.
- The results of a semi-quantitative effectiveness evaluation conducted on an undergraduate structural geology class generally indicates a reduction in student misconception pertaining to the state of three-dimensional strain following the FRY3D tutorial.

8. References

[1] N. Fry. Random point distributions and strain measurement in rocks. Tectonophysics, 60(1-2):89–105, 1979.

[2] P. Launeau and P.Y.F. Robin. Determination of fabric and strain ellipsoids from measured sectional ellipses–implementation and applications. Journal of structural geology, 27(12):2223–2233, 2005.

[3] Jonathan M. Lees. RFOC: Graphics for Spherical Distributions and Earthquake Focal Mechanisms, 2011. R package version 2.0-00.

[4] J. R. Webber. StructR: Structural geology tools, 2012. R package version 1.1.