Print Your Compass: Using 3D Printed Geological Compasses for Teaching and Research Purposes

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MOTIVATION

A geological compass is an essential tool in the geologist's field kit. It is used in various geosciences disciplines, including geological mapping and structural geology. The past decade has seen the emergence of digital geological compasses through excellent smartphone or tablet apps (e.g., FieldMove Clino, eGeoCompass, Stereonet Mobile), the reliability of which has been demonstrated for teaching and research purposes (e.g., Novakova and Pavlis, 2019; Lundmark et al., 2020). Although these digital compasses are highly ergonomic and have greatly improved the speed and the rate of data collection (Zobl et al., 2007; Allmendinger et al., 2017), it is essential that undergraduate students learn how analog geological compasses work and how to use them to characterize the orientation of given geological structures (i.e., foliations, lineations, or a combination of both) and transcribing this information in the right format in a notebook. What is the minimum requirement for a geological compass? It must be equipped with a clinometer, a precision magnetometer—ideally with a fixed circular graduation—a measuring reference trench, and a bubble level. Various geological compasses are available on the market (e.g., Brunton, Freiberg, Topochaix brands) with several models in different price ranges. Nevertheless, equipping large student groups with robust, accurate, semi- to fully professional models of geological compasses still represents a significant cost. This is why I initiated the PYC (Print Your Compass) project, building upon the emergence of affordable digital fabrication tools such as 3D printing, which is particularly facilitated by the development of shared workspaces such as FabLabs and creation networks in academic institutions and/or universities (Hasiuk, 2014; de Lamotte et al., 2020; Reynolds et al., 2020).

This paper aims to provide detailed 3D plans of compass pieces, guidelines for printing materials, magnets and pivot system, and validating the accuracy of printed compasses. I hope that such initiatives will allow students from their first degree to master's level, teachers, and geoscientists in general, to print their geological compass at a lowered cost, adapted to their specific needs, and with sustainable manufacturing.

HOW TO PRINT YOUR COMPASS

The PYC compass (v.0.94) presented in Figure 1A is designed in five modules. Part 1 is the core of the compass, printed here using Selective Laser Sintering (SLS) in rigid Nylon Polyamide (PA12) with a printing resolution <80 µm. The front side of Part 1 is made of a cylindrical cavity embedding the precision compass, and the back side is marked by a circular gully in which a 2-mm-wide brass ball will be used as a clinometer. Part 2 comprises the magnet and pivot system. It is made of a pile of three stacked pieces printed using SLS–PA12 (Fig. 1A) in which a brass pivot and four Nd-magnets (15 mm long × 3 mm in diameter) are enclosed. The magnet and pivot system is ultimately stacked and sealed by two vertical nylon screws. The magnet and pivot system is balanced on a brass nail crossing Part 1 vertically. Part 3 and Part 4 are the closing windows placed on each side of the PYC compass. They both consist of a 2-mm-thick and 80-mm-side square plexiglass window. They are crucial parts of the compass as they display the graduations for precise measurements. Part 3 comes with inclination degrees from 0 to 90° (with a precision of 2°), and Part 4 is graduated from 0 to 360° for azimuth measurement respective to north (with a precision of 1°). Graduations can be directly printed onto plexiglass pieces or as transparent flipped vinyl stickers placed on their inner side. Small nylon screws are used to fix these windows to the main part of the PYC compass. Part 5 comprises two levels and the casing of the PYC compass. One rounded level (15 mm in diameter and 8 mm in height) can be embedded on the front side of the PYC compass to enable levelling, along with a second cylindrical level on the side of the PYC compass to improve finding the line of slope on a planar structure. The protection case, printed here in a flexible resin (thermoplastic polyurethane), is designed to laterally slide the PYC compass in it and act as a shock absorber. The whole compass is 10 × 10 × 2.3 cm in size and weighs less than 0.25 kg. It can be easily disassembled, and each of the constitutive pieces can be replaced. The 3D models can be found in the supplemental material[1] or here: https://skfb.ly/opCJY. These are licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

VALIDATING THE PYC COMPASS ACCURACY IN THE FIELD

I tested the PYC compass in the field and compared measurements against reliable compasses, including the Topochaix Universelle compass and the FieldMove Clino app running on a Samsung S7 smartphone. The test was conducted on the Moulin de Cezinieux orthogneissic unit located in the northern Pilat region (eastern French Massif Central; Fig. 1B). This outcrop is made of low-dipping metamorphic foliations from the late Hercynian orogenic

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[1]Supplemental Material. 3D models (as .obj filetype) for each part of the PYC compass. For more details about these files, please contact the author: antoine.triantafyllou@univ-lyon1.fr. Go to https://doi.org/10.1130/GSAT.S.16900333 to access the supplemental material; contact editing@geosociety.org with any questions.

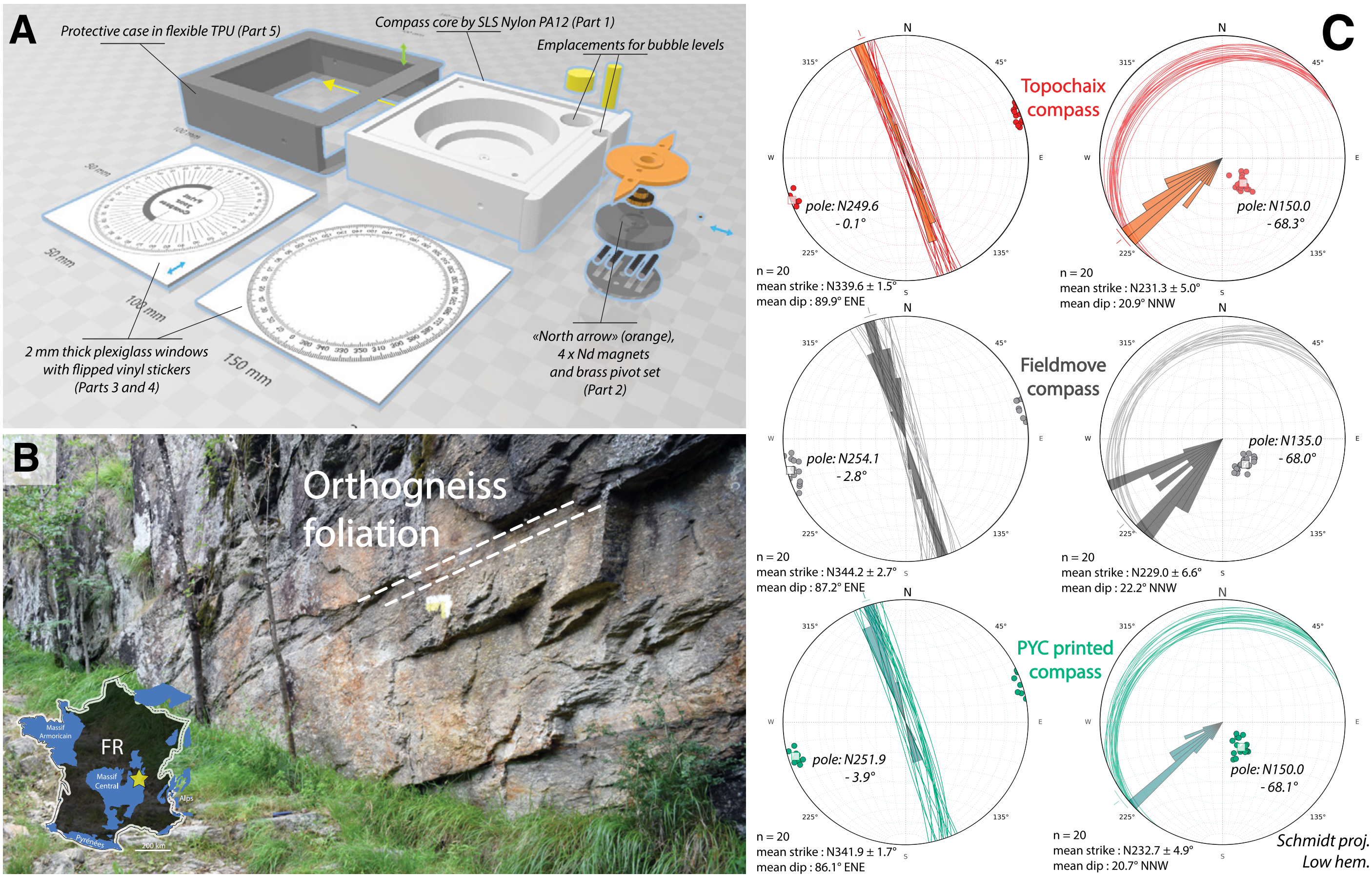

Figure 1. (A) Disassembly view of the "Print Your Compass" (PYC) 3D models. (B) Field picture showing the outcrop on which the PYC compass was tested. The outcrop displays an augen orthogneiss massif with foliations slightly dipping to the NNW, itself crosscut by late joints and faulted structures. Lower left is a sketch map of the French basement in blue locating the French Massif Central and the investigated outcrop (yellow star). (C) Two columns of comparative Stereonet plots. The first column shows measurement of the subvertical joints and faults, the second shows the measurement of foliations. Poles of planes are shown with the average value as a blank square. Rose diagrams show the distribution of strikes' azimuths. These plots were done using the Geolokit app (Triantafyllou et al., 2017).

collapse (e.g., Gardien et al., 2021). These ductile structures are crosscut by recent subvertical joints and faults. Tests were made on these two types of structures with twenty planar measurements for each compass: (i) Concerning foliation measurements, using the FieldMove digital compass, the mean strike direction is N229.0 ± 6.6° (95% polar confidence), and the mean dipping value is 22.2° to the NW. For the Topochaix Universelle compass, the mean strike direction is N231.3 ± 5.0°, and the mean dip is at 20.9° to the NW. For the PYC printed compass, the mean strike direction is at N232.7 ± 4.9° and the averaged dipping value was 20.7° to the NW with a radius of polar confidence at 5% of 2.35° (Fig. 1C). (ii) Concerning the subvertical joints and faults measurements, the FieldMove digital compass provides an averaged strike direction of N344.2 ± 2.7° and a mean dip at 87.2° to the E. For the Topochaix Universelle compass, the mean strike direction trends to N339.6 ± 1.5°, and the mean dipping value is 89.9° to the E. The PYC compass provides a mean strike direction at N341.9 ± 1.7° and an averaged dipping value at 86.1° to the E (see Fig. 1C). The reliability of the PYC compass is attested first by the small polar differences between PYC mean pole values and those measured with the Topochaix and the FieldMove Clino app, which yields 4.4° and 2.5°, respectively, for the foliation structures and 0.2° and 15.0°, respectively, for the joint/faulted structures; and second by the small radius of polar confidence at 5% of 2.35°, indicating a reduced data spread and a good reproducibility during structures measurement.

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Geology Celebrates 50 Years in 2022

Volume 1, issue 1, of *Geology* was published in September 1973. This month, the journal publishes the first issue of its 50th volume. A bit of an upstart at the time, *Geology*'s mission was to be a "short-note, rapid publication journal." Along with short, peer-reviewed articles, early issues included book reviews, letters, and summaries of *GSA Bulletin* papers. In 1975, a section called "GSA news & information" was added. (*GSA News & Information* became its own publication in 1979; was ultimately replaced with *GSA Today* in 1991.) Read more about *Geology*'s beginnings at **https://pubs.geoscienceworld.org/geology/issue/50/1.**

September 1973 cover. Lunar Orbiter V, Photo 65 M, showing Hess Lunar Crater.

January 2022 cover, celebrating Geology's 50th year of publication.