26445 - Structural Geology

Información del Plan Docente

Academic Year	2018/19
Subject	26445 - Structural Geology
Faculty / School	100 - Facultad de Ciencias
Degree	296 - Degree in Geology
ECTS	9.0
Year	2
Semester	First semester
Subject Type	Compulsory
Module	---

1.General information

1.1.Aims of the course

The expected results of the course respond to the following general aims

The general goals of the subject are brought up at three levels:

(a) Learning of conceptual and methodological aspects through theoretical and practical classes (deductive learning)

(b) Practical use of techniques for analytical treatment and plotting of structural data.

(c) Development of research capabilities using empiric methodologies, from field-data collection to final interpretation.

General goals:

The student should:

1) know the different types of tectonic structures: definitions, classifications; as well as geometric, kinematic, and dynamic characteristics at different scales.

2) develop observation abilities and collect field data.

3) learn the main techniques to represent and analyze tectonic structures.

4) know how to apply the concepts and models of Structural Geology to regional scale interpretations.

5) be able to work alone and in a group.

6) learn to be critical with scientific information, and be able to express clearly his/her scientific results.

1.2.Context and importance of this course in the degree

Structural Geology is a fundamental tool to decipher the geology of deformed areas and thus it should be considered an indispensable knowledge for any geologist. On the other hand, Structural Geology deals with geometrical aspects of deformation and thus it is closely related with disciplines like Geological Mapping, Geophysics and Tectonics.

1.3.Recommendations to take this course

This branch of the Geology requires the development of a 3-D visualization of the tectonic structures, as well as observation and interpretation abilities both in the lab and in the field. This course in Structural Geology values the comprehension and the reasoning capabilities as much as the rote learning.

2.Learning goals

2.1.Competences

After completing the course, the student will be competent in the following skills:

Recognize, describe and classify the main tectonic structures.

Interpret the genetic mechanism of the studied structures.

Apply the most appropriate geometric, kinematic or dynamic method to study a specific structure or group of structures.

Identify in the field deformational structures and their geometric elements.

Collect structural data in the field. Be able to recognize outcrop and regional scale structures and to draw schemes and geologic cross-sections. Measure linear and planar elements in the field.

Identify deformational structures at hand and thin-section scale.

Have a good command of the main structural techniques related with the representation and analysis of geometric data: stereographic projection, orthographic projection, cross sections, block diagrams, contour maps.

Reconstruct the genetic mechanisms of real structures, as well as their kinematic and dynamic evolution, and in the case of poliphasic deformations, their chronological sequence.

2.2.Learning goals

The student, in order to pass the course, will have to show her/his competence in the following skills:

Identify the main type of tectonic structures as well as to know their geometric characteristics and genetic mechanisms

Construct geologic maps as well as schemes showing the geometry and relationship of the structures in the field

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Measure the attitude of planes and lines using the geologic compass

Represent and read structural elements (planes and lines) by means of orthographic projection, stereographic projection and cross sections

Find and read scientific articles as well as select and understand the most relevant information.

Work alone and in a group, as well as to defend scientific results with reasonable arguments.

2.3.Importance of learning goals

Geologic structures provide part of the basis for recognizing and reconstructing the profound changes that have marked the physical evolution of the Earth's outer layers, as observed from the scale of the plates down to the scale of the microscopic. Understanding the nature and extensiveness of deformational structures in the Earth's crust has both scientific value and practical benefit. But, there is a philosophical value as well. Our perceptions of who we are and where we are in time and space are shaped by facts and interpretations regarding the historical development of the crust of the planet on which we live. Knowing fully the extent to which our planet is dynamic, not static, is a reminder of the lively and special environment we inhabit .... Once the conceptual framework within which structural geologists operate is grasped, the Earth begins to look different. In fact, natural physical processes and natural physical phenomena, whether geologic or not, never quite look the same again (*from Davis and Reynolds, 1996*).

3.Assessment (1st and 2nd call)

3.1.Assessment tasks (description of tasks, marking system and assessment criteria)

The student will prove that he/she has achieved the expected learning results by means of the following assessment tasks:

ASSESSMENT OF STUDENTS THAT ATTEND CLASS REGULARLY

To track the improvement and knowledge of the students, part of the assessment will be carried out during the learning process (continuous assessment) and part at the end of the course (final assessment)

1. Continuous assessment

1) *Question papers/questions for oral answer.* The students will have to answer to question papers or questions for oral answer, alone or in groups, dealing with conceptual and methodological aspects. This activity will be mainly related with the seminar exercises. (Evaluation of skills 1, 5 and 6).

2) *Laboratory exercises.* The practical exercises carried out in the lab will be corrected every week. (Evaluation of skill 4).

3) *Field work.* The attendance to the field trips is compulsory. The personal work, expressed in the student's note-book, and the attitude of the student in the field, will be evaluated. (Evaluation of skills 2, 3 and 6).

2. Final assessment

4) Written exercises. A theoretical-practical exercise and a practical exercise will be carried out during the period of exams (4-5 hours). The theoretical-practical exercise will be constituted by two parts: a) a test and/or a set of short questions, and b) questions that, in most cases, may be answered by means of drawings. The practical exercise will be closely related with the practical sessions of the course. (Evaluation of skills 1, 2 and 4).

ASSESSMENT OF STUDENTS THAT DO NOT ATTEND CLASS REGULARLY

Global assessment

Those students that have not attended the course regularly, as well as those who wish to, may take a global exam:

February exam: It may be an oral (speaking) exam or a written exam. The evaluation may include any activity related to field work.

September exam: It may be an oral (speaking) exam or a written exam. The evaluation may include any activity related to field work.

1) oral exam or a written exam. Duration of the exam: 3-5 hours.

2) a practical exam where the student will have to solve laboratory and field exercises similar to those carried out during the course. Duration of the exam: 3-5 hours.

Assesment criteria

(a) Assessment of the course for students that attend classes regularly:

As a general rule, to pass the course it will be necessary to:

1.- Participate in the laboratory and seminar activities and attend the field trips.

2.- Obtain a grade higher than 5 in the theoretical-practical exam.

3.- Obtain a grade higher than 5 in the practical exam.

Evaluation of skills:

- Lab work: 5 %

- Seminars:15 %

- Field work: 5 %

- Practical exercise: 35 %

- Theoretical-practical exercise: 40 %

(b) Assessment of the course for students that do not attend classes regularly:

- Written exam: 50 %

- Practical exam: 50 %

4.Methodology, learning tasks, syllabus and resources

4.1.Methodological overview

The learning process that has been designed for this course is based on the following activities:

The program of the subject is just the framework that should guide the active learning of the students. The students will have class-notes given by the professor as the basis for their learning, but they must extend the information given in class using that coming from technical books and scientific journals. The practical learning will prevail over the theoretical one. The laboratory sessions will be mainly devoted to the analysis of the most common tectonic structures. The field work will focus on the recognition of the studied structures, the determination of their geometries, structural relationships, ages, ..., and the obtained data will be represented on the student's note-book by means of tectonic schemes, cross-sections, etc, and by simple geological maps. The tutorials will be considered another academic activity where the student will be free to ask any doubt related with the subject.

It is important to note that the specific terminology used in this course will also be taught in Spanish.

4.2.Learning tasks

The programme offered to the students to help them achieve the learning results includes the following activities:

Activity 1. Conceptual, descriptive and genetic aspects of tectonic structures. The most common geometric, kinematic and dynamic methods.

Methodology: **Theoretical-practical classes** (3 ECTS) and **Seminars** (0,5 ECTS) for oral presentations and discussions.

Activity 2. How to analyze meso and micro-scale structures. Reconstructing and analyzing the geometry, kinematic and dynamic of tectonic structures.

Methodology: **laboratory sessions** (2,5 ECTS).

Activity 3. How to function in the field.

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Methodology: **Field work** (3 ECTS)

4.3.Syllabus

I. PROGRAM OF THEORETICAL CLASSES

Part 1: INTRODUCTION

1. Introduction to the course. Structural Geology, Tectonics and Global Tectonics: history, goals and methods. Geometry, kinematics and dynamics in Structural Geology.

2. Lines and planes in Structural Geology. Orientation of lines and planes. True and apparent dips. Field notes (conventional symbols). Analysis of the orientation of lines and planes. The Stereographic projection.

3. Stress. Definition of force and units. Definition of stress and units. Simple calculation of stress. Lithostatic stress. Stress due to contact forces. Components of stress. State of stress in a point. Tensor and stress ellipspoid. Types of state of stress. Resolving the state of stress on a plane. Mohr stress diagram. Mean stress, deviatoric and differential stress. Stress field and stress trajectories.

Part 2: DUCTILE STRUCTURES

4. **Strain**. Definition and types of deformation. Classification of internal deformation: continuous/discontinuous, fragile/ductile, and homogeneous/inhomogeneous. Vector, trajectory and displacement field. Finite, infinitesimal and progressive deformation. Measuring and representing deformation: rigid body deformation (translation, rotation) and non-rigid-body deformation (longitudinal strain, shear strain and dilation). The strain ellipsoid: types of strain ellipsoids. Flinn's diagram. Spacial terms in strain (coaxial, non-coaxial; rotational, non-rotational; pure and simple shear). Progressive deformation and the length of deformed lines. Zonation of the finite strain ellipse. The fundamental strain equations. The Mohr strain diagram.

5. Ductile deformation processes. Ductile deformation. Cataclasis/Cataclastic flow. Crystal plasticity (dislocation migration, mechanical twinning). Diffussional mass transfer (volume-diffusion creep, grain boundary diffusion creep, superplastic creep; pressure solution. Deformation microstructures (recovery, dynamic and static recrystallization), neomineralization. Deformation mechanisms and physical conditions during deformation (deformation maps).

6. **Rheology and mechanical behavior of rocks.** Definition. Strain rate. Laboratory deformational experiments (compressional and extensional tests). Duration of deformational experiments (long and short term deformational experiments). Short duration lab experiments: elastic and plastic behavior, yield stress/strength, rupture strength); strain/work hardening, strain softening, ultimate strength. Long duration lab experiments: creep (primary, secondary, tertiary). Rheological relationships (linear and non-linear rheologies): Elastic behavior, viscous (viscoelastic, elastico-viscous, general behavior), ideal plastic behavior and elastic-plastic. Factors that influence the mechanical behavior of rocks: lithology, temperature, confining pressure, time, the magnitude of stress, strain rate, pore fluid pressure (effective stress). Classification of rocks according to their rheological behavior (brittle and ductile, competent and incompetent). Rheological behavior and depth: structural levels.

7. **Rock fabrics**. Introduction: concept of fabric. Classification of fabrics (primary, secndary; isotropic, anisotropic;

mesoscopic. microscopic; crystallographic; penetrative, non-penetrative; dimensional. Types of dimensional fabrics (planar, linear, double fabric). Tectonites (L, S, S-L, S-C) . Cleavage. Types of cleavage: disjunctive (space, stylolitic, rough cleavage, crenulation clevage); continuous cleavage (slaty, phyllitic cleavage, and schistosity); gneissic structure. Genetic mechanism of cleavage. Tectonic meaning of cleavage (cleavage fans, axial plane cleavage, cleavage refraction). Lineations. Most common lineations: intersection, crenulation, stretching and mineral lineations. Some linear structures: mullions and boudinage.

8. **Folds**. Definition and tectonic environment. Scientific and economic interest. Geometrical and physical elements (parts of a fold: hinge point, line, zone; flanks, core, inflection points-lines, curvature, axial surface, etc). Elements of a folded surface (crets point-line, trough point-line, culminations and depressions, etc). Size of an isolated fold/train of folds (wave length-amplitude). Fold description: shape, tightness, size and attitude. Fold clasifications according to: a) relative age of the rocks, b) direction of the concavity/convexity, c) fold shape (Hudleston, 1973), d) form of the fold, geometry of the axial surface, e) symmetry (vergence), f) fold attitude (Fleuty diagram), g) fold tightness, h) changes of wave length and/or amplitude. Ramsay's classification; Ramsay's diagram. Fold termination. Large scale folding (anticlinorium, synclinorium, fold belts, ...). Superposed folding. Fold interference pattern. Folding style.

9. **Folding mechanisms and kinematic models**. Acitve and passive folding. Three mechanisms and five kinematic models of folding at meso-macroscopic scale: Flexure (flexural-slip, flexural flow and volume-loss folding); fold shape modification by superimposed homogeneous strain; flow (simple shear transverse to bedding; shear folding. 1) Flexural-mechanism: bending and buckling. Internal strain in flexural folding: Longitudinal strain in the hinge zone and shear strain in the flanks. Flexural flow folds. Volume loss folds. 2) Flattening-mechanism: homogeneous and inhomogeneous. Cleavage associated to flattening. Combination of flexure and flattening. 3) Flowage-mechanism. Types of deformation by flow. Shear folding. Tectonic environment and folding. Donath and Parker (1964): genetic classification. Some special types of folding: kink folds and drag folds.

Part 3: BRITTLE STRUCTURES

10. **Rock mechanics/rock fracturing**. The fundamental fracture modes (modes I, II, and III). Intoduction to rock mechanics (tensile and compressive strength tests); Mohr diagram and envelope of failure. Constructing an envelope of failure: tensile strength tests, tensile and compressive strength tests transitional tensile behavior, parabolic failure envelopes). Griffith's law of fracture criterion. Compressive strength tests-Coulomb's fracture criterion. Application of the Murrel and Coulomb fracture equations. Compressive tests raising confining pressure; von Mises' fracture criterion. Grand failure envelope. Effective stress: the influence of pore fluid pressure. Testing prefractured rocks (Failure envelope for frictional sliding, coefficient of sliding friction, ..., Byerlee's law). Classification of fractures and physical discontinuities. Brittle fractures and the Mohr circle.

11. **Joints and shear fractures.** Definition. Geometry: form of the joint surface. Classification of joints considering: a) general characteristics (joint set, joint system); b) angular ralationship between joints (Hancock, 1985); c) characteristics of the opening. Joint-face ornamentation: plumose markings (origin, hackles, ribs, fringes, ...). Joint spacing; spacing/bed thickness. Some criteria to determine the relative chronology. Recording joint data. Dynamic interpretation of joints and shear fractures: joints, shear fractures and the Mohr circle.

12. **Stylolites surfaces and extension veins.** Definition of stylolitic surface and stylolite. Geometry of stylolites and stylolitic surfaces; normal and oblique stylolites; bedding and transverse stylolites. Slickolites. Genesis of stylolitic surfaces: pressure solution mechanism. Stylolitic surfaces/stylolites and the stress tensor. Definition and characteristics of extension veins. Criteria to determine the extension direction (tension vein texture; syntaxial and antitaxial crystal fiber veins). Tension gashes and shearing; tension gashes and folding. Extension veins and the stress tensor. Relationship between stylolites and extension veins: dynamic implications.

13. **Faults**. Definition of fault, fault zone and ductile shear zone. Classification based on: a) the fault surface geometry-attitude; b) hangingwall movement (rotational, non-rotational). Geometric elements of faults (tip point-line; blind fault, exposed fault, fault scarp, .., cut-off poit-line, ..)The slip of a fault and fault separation. Net slip: components (heave, throw). Classification of faults considering the slip components (dip-slip, strike-slip, oblique-slip, scissor-like or rotational). Naming oblique-slip faults. Criteria to identify the direction and sense of displacement of a fault (from the fault surface: striations, slickolites, grooves, crystal fiber lineations, ... ; carthographic criteria: orthographic and stereographic projections; structures related to the fault kinematics: drag folds, ...). Extensional and contractional faults. Fault systems (branch point/line). Horses and duplexes. Conjugate faults; synthetic and antithetic faults. Kinematics of crossing conjugate fault sets. Anderson's theory of faulting: relation between conjugate faults and the principal stress axes. Fault reactivation and inversion tectonics. Fault rocks: brittle (breccias, cataclasites, pseudotachylites) and "ductile" (mylonitic) fault rocks.

14. Thrusts and reverse faults. Definition and general characteristics. Geometric elements and types of thrusts (thrust-sheet, backthrust, nappes, ...). Thin and thick-skinned tectonics. Map view (klippe, tectonic window, breached window). Geometric characteristics of staircase-like thrusts. Types of ramps (frontal. oblique, lateral). Associated folding: fault-bend folds; fault-propagation folds, trishear folding; detachment folds; break-thrust folds). Thrust systems; terminology (foreland, hinterland, duplex roof-floor, antiformal stack, imbricates fans, ...). Relay zones and transfer faults. Thrust kinematics: criteria to determine the transport direction and the age of the structure. Syntectonic or growth deposits/synsedimentary or growth structures. Geometry of syntectonic deposits (onlap, offlap, thinning-thickening, syntectonic unconformity, progressive unconformity; Riba, 1976). Thrust sequence (break-back, foreward-breaking, out of sequence). Palispastic restoration and shortening calculation. Tectonic environment for thrust faulting.

15. Normal faults. Definition and general characteristics. Geometric elements. Meso-macro-scale structures associated to normal faults: roll-over anticlines, fault-bend folds, drag folds, extensional duplexes, release faults, transfer faults, ... Regional-scale normal-fault systems (Graben, horst, half-graben, detachment fault, synthetic/antithetic faults, ...); pseudo-rollover/compensation graben, imbricate listric fan. Basic kinematic models of normal faults. Normal fault sequences. Determining stretching caused by normal faults. Tectonic environment.

16. Strike-slip faults. Definition and general characteristics. Strike-slip shear zones and associated structures (e.g. Riedel shears, P and R' shears among others). Bends and step-overs in strike-slip fault zones; geometry and terminology. Pull-apart basins and pop-ups. Strike-slip duplexes (flower structures). Tectonic environment for strike-slip faulting (..., tear faults, transform faults, escape tectonics, ...). Modelling of shear zones (Tchalenko, 1970).

Part 4: Seminars

17. The nature of shear zones and types of shear zones.

18. Salt structures. Diapirs.

19. Gravitational structures.

20. Impact structures. Meteorites.

21. Superposed folding.

22. Tectonic structures in plutons.

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23. Non tectonic structures in Structural Geology

II. PROGRAM OF LABORATORY SESSIONS

1. Geologic cross sections (I) constructed from geologic maps with folds, normal faults and unconformities.

2. Geologic cross sections (II) constructed from geologic maps with folds, thrust faults and angular unconformities.

3. Geologic cross section. Recumbent fold. Geologic history of different geologic cross-sections.

4. Stereographic projection (I). Lines and planes. Poles to planes. True and apparent dips. Pitch of a line. Intersection between planes.

5. Stereographic projection (II). Angles between lines and planes. Projection of lines onto planes. Fitting lines and planes to small and large circles. Tilting and rotations.

6. A) Tectonic fabrics: Identifying linear and planar elements. Relationship with the strain ellipsoide. B) Orthographic projection: True and apparent dips. Three points problem.

7. Density diagrams. Using a dendity diagram to calculate a fold axis. Determining the paleo-orientation of a fold situated below an angular unconformity.

8. 3D methods (I). Contour maps. Stress analysis using Mohr circle in 2D (homework)

9. Computer programs: using computer programs to plot lines and planes as well as to determine their geometric relationships. Density diagrams.

10. Riedel experiment: shear zones in semibrittle rocks.

III. PROGRAM OF FIELDTRIPS

Field Trip 1

- Locality: Vadiello (Huesca); Mesozoic and Cenozoic.

- Date: see the academic calendar approved by the Departamento de Ciencias de la Tierra

- Activities: Collecting field data along a structural traverse in the External Sierras. Study of brittle tectonic structures. Tecto-sedimentary relationships. Construction of a geolocical cross section.

Field Trip 2

-Locality: Isuela - Pico del Águila (Huesca); Mesozoic - Cenozoic.

- Date: see the academic calendar approved by the Departamento de Ciencias de la Tierra

- Activities: Construction of a regional scale cross-section. Study of brittle tectonic structures. Synsedimentary structures.

Field trip 3

- Locality: Aliaga (Teruel); Cretaceous and Tertiary.

- Date: see the academic calendar approved by the Departamento de Ciencias de la Tierra

- Activities: Study of poliphasic deformation. Geometric and kinematic reconstruction of superposed folding. Tecto-sedimentary relationships.

Field trip 4

-Locality: Montalbán-Molinos (Teruel); Mesozoic and Cenozoic.

- Date: see the academic calendar approved by the Departamento de Ciencias de la Tierra

- Activities: Construction of a regional cross section of a thrust system and associated folds. Study of brittle structures (faults, stylolites, extension veins): Field schemes, measuring of linear and planar elements, timing of deformation.

Field trip 5

- Locality: Cerveruela - Puerto de Paniza (Zaragoza); Paleozoic.

- Date: see the academic calendar approved by the Departamento de Ciencias de la Tierra

- Activities: Study of ductile and brittle tectonic structures.

4.4.Course planning and calendar

The 9 ECTS of this subject correspond to 90 hours of presential education, which will be arranged in the following way:

- 30 hours of theoretical classes (3 h /week)

- 5 hours of seminars.

- 25 hours of lab sessions (2.5 h / week, 10 sessions).

- 30 hours of field-work

This course is a first semester course. Classes will start the first academic week.

Students can refer to the Faculty of Sciences and Earth Sciences Department websites (https://ciencias.unizar.es; https://cienciastierra.unizar.es/) for timetable, classroom or assessment dates.

Further information regarding this course (examination, individual or group assignments...), will be provided on the first day of class.

Dates for each field trip will be published at the Earth Sciences Department website.

Tutorials: Office hours will be also provided the first day of class.

4.5.Bibliography and recommended resources