Universitat Autònoma de Barcelona

2021/2022

Metamorphic Petrology

Code: 101057
ECTS Credits: 6

Degree	Type	Year	Semester
2500254 Geology	OB	3	2

The proposed teaching and assessment methodology that appear in the guide may be subject to changes as a result of the restrictions to face-to-face class attendance imposed by the health authorities.

Contact

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Use of Languages

Principal working language: catalan (cat)
Some groups entirely in English: No
Some groups entirely in Catalan: Yes
Some groups entirely in Spanish: No

Prerequisites

Remarcably, students must have acquired the previous competences related to previous matters as Fundamentals of Geology, Chemistry, Physics, Mathematics, Mineralogy, Petrology (Sedimentary and Igneous), Geochemistry and Structural Geology I.

In particular, the following concepts are recommended to be fresh:

- A basic knowledge on the Earth internal structure, Minerals and Rocks, Internal Geological Processes, Metamorphism and Magmatism
- Fundamentals of Thermodynamics and Chemical Kinetics, in particular those related to solid-solid reactions or basic phase diagrams knowledge
- Energy in the form of work and heat
- The systems of equations, matrix algebra and calculus (functions and their derivation and integration)
- The composition, crystal Structure and crystal-chemistry of the main rock forming Minerals and its main genetic environments
- Basic concepts in Optical mineralogy
- The classification, nomenclature, main mineralogical, textural and geochemical characteristics and the genesis of the main igneous and sedimentary rocks
- The geochemistry of diagenetic and endogenous processes (magmatic, metamorphic and interaction between fluids and rocks at high pressures and temperatures, Stress-strain relationships, rheology, main characteristics of the fragile and ductile regimes of deformation and the different structures related to both regimes, their description at different scales and their graphical representation through schemes or maps.

Objectives and Contextualisation

The main objectives of the subject are:

- Learn the characteristics of metamorphism and metamorphic rocks: mineralogical, textural, geochemical, genesis and geotectonic contexts.
- Learn to classify and name the different types of metamorphism and metamorphic rocks.
- Learn the basics of the modern methods in Metamorphic Petrology and its main historical landmarks.

- Learn to identify and interpret the microstructures of metamorphic rocks in hand sample and the petrographic microscope.
- Learn the different processes and factors that characterize petrogenesis of metamorphic rock and the tools to characterize them.
- Learn to identify the different types of metamorphic rocks in hand samples and the microscope.
- Learn to describe and represent graphically and interpret the petrographic data on mineralogy and texture and the geochemical observation datasets.
- Learn the basics of the integration of observation data with petrogenetic theory, in a quantitative way, using physic-chemical, mathematical and computer science tools.

- Theory:

Unit I - To have a global vision of metamorphic phenomena, emphasizing the following aspects: definition, typology, types of geological contexts, relationships with global tectonics and the relation and coexistence with fluids and to kinetic variables. To know the basics of the nomenclature of the metamorphic rocks and of the work methodology.

Unit II - To know the theoretical basics of the chemical-mineralogical and textural analysis and how they are used to find out the evolution of metamorphic rocks. Learn how to gain information on non-observable variables such as pressure and temperature of formation, age of metamorphism and characteristics of the fluid present during metamorphism from observable variables as the chemical-mineralogical and textural data.

- Laboratory Practicals: Know how to recognize metamorphic minerals (main silicates and non-silicates) in the thin section, in hand sample (a representative set), metamorphic microstructures and the main types of metamorphic rocks (both aspects in the thin section and in hand sample). Know how to apply the nomenclature of metamorphic rocks. Understand the basic tools of representation and description of metamorphic mineral assemblages.

- Field Practicals: Know the fundamental tools of the field study of metamorphic rocks. Learn to recognize the main minerals, textures and rocks in their outcrops.

Competences

- Draw up and interpret geological maps and other means of depicting geological information (columns, correlation frames, geological cross-sections, etc.)
- Identify and characterise minerals and rocks through instrumental techniques, determine their formation environments and know their industrial applications.
- Learn and apply the knowledge acquired, and use it to solve problems.
- Process, interpret and present laboratory data using qualitative and quantitative techniques, and suitable computer programmes.
- Show an interest in quality and incorporate it into practice.
- Suitably transmit information, verbally, graphically and in writing, using modern information and communication technologies.
- Synthesise and analyse information critically.
- Work independently.

Learning Outcomes

1. Learn and apply the knowledge acquired, and use it to solve problems.
2. Present arguments based on phase diagrams.
3. Recognise the principal types of rocks in hand specimen and using a petrographic microscope.
4. Relate each type of rock to its genesis and the temporal dimension.
5. Relate field observations of minerals and rocks to laboratory observations and to genetic theory, based on the textures.
6. Show an interest in quality and incorporate it into practice.
7. Suitably transmit information, verbally, graphically and in writing, using modern information and communication technologies.
8. Synthesise and analyse information critically.

9. Work independently.

Content

THEORY:

Unit I. FUNDAMENTALS

L1. Metamorphism. Definition. General context. Limits. Causes: steady state, perturbations and transient states of the Lithosphere Geothermal function. Factors: pressure, temperature, fluid, stress-deformation, bulk composition. Types of metamorphic changes: mineralogical change and textural change.

L2. Types of metamorphism. Relationship with plate tectonics. Regional metamorphism in divergent plate margins: burial metamorphism, ocean ridge metamorphism. Regional metamorphism in convergent plate margins: orogenic metamorphism. Subduction and collision stages. Local metamorphism: contact metamorphism, high-strain metamorphism and impact metamorphism.

L3. Nomenclature of metamorphic rocks. Basic structure. Terms referring to the Protholit. Terms that refer to textures and fabrics. Special terms: mineralogical complements Terms relating to P-T conditions. Conclusions.

L4. Methodology *. Summary of the history of the Metamorphic Petrology. The modern method: Limitations, types of approaches: empirical, experimental and theoretical. Introduction to Metamorphic Petrogenesis: observable and non-observable variables. The equilibrium model. Objectives of the Metamorphic Petrology. (*) Recommended reading of a book chapter or paper.

Unit II. FACTORS AND VARIABLES

L5. Texture and Fabric. Introduction: definitions and nomenclature. Mass transfer. Diffusion. Nucleation, growth and resorption. Deformation. Textures of static recrystallization: granoblastic, nonpyroclastic. Reaction textures. Deformational textures: Foliations and lineation's. Cataclastic and mylonitic textures. Crystallization-deformation relationships.

L6. The mineral assemblage. Definitions. Mineral equilibria: Evidence. The Phase rule. The mineral composition: phase components. Compositional spaces for silicates: relationships with its crystal structure. The bulk composition of metamorphic rocks: System components. Mode. The relationship between mode, mineral composition and bulk composition. Representation: compatibility diagrams. Index minerals and key assemblages. Metamorphic grade. Zones and Isograds. Metamorphic reactions. The metamorphic Facies: historical and current vision of the concepts. Facies Series. Metamorphic field gradient (MFG).

L7**. Pressure, temperature and time (P-T-t). Lithostatic pressure vs. stress. The Lithospheric Geotherm and heat flow. Geotherm estimation using surface measures. Theoretical calculation of Geotherm. The heat flow equation. P-T-t Paths. Simple models for P-T-t evolution: model of a laminar magmatic intrusion, crustal thickening models of collisional orogens and mixed models of crustal thickening with magmatic intrusions. Duration of the metamorphic events. Characteristic velocities: kinetic metamorphic changes. Geochronology concepts. The closing temperature. Dating methods. The P-T-t paths and their relation to Geotherm and MFG.

L8**. Fluids. Introduction. Importance. Evidences of its existence during metamorphism. Characteristics of the fluid phase: quantity, physical state, composition, location. Mechanisms of mobility. Influence of fluids on metamorphic reactions: internal control vs. external control.

* * The concepts related to these topics on the factors P-T-t-f will be introduced throughout the course, therefore in L7-L8 there will be more focusing on more advanced concepts, not developed during the course, allocating each a variable amount of time, depending on the total time available at the end of the semester.

PRACTICAL SESSIONS:

Unit I. Microstructures of metamorphic rocks

Practical 1. Granoblastic microstructures. Procedures for textural analysis of metamorphic rocks. Polygonal granoblastic microstructure. Decussate granoblastic microstructure. Nonpyroclastic microstructure with a granoblastic polygonal or decussate (or mixed) matrix.

Practical 2. Reaction microstructures. Compositional zoning in metamorphic minerals. Overgrowths and coronas. Pseudomorphism. Simplectites. Exsolution lamellae.

Practical 3. Deformational microstructures. Oriented Granoblastic. Lepidoblastic. Nematoblastic. Porphyroblastic with oriented matrix.Porphyroclastic mylonitic and cataclastic.

Unit II. Metamorphic Rocks

Practical 4. Metabasites. NCFMASH system and ACF diagram. Petrogenetic grid. low to medium P facies series: greenschists. amphibolites and garnet bearing amphibolites, mafic granulites. High P facies series: Blueschists. Low-T eclogites, eclogites and retroeclogites.

Practical 5. Metapelites. KFMASH system and influence of other elements (Mn, Ca, Na). The AFM Diagram. Petrogenetic grid. Metapelites of the medium P facies series (Barrow): Slates - Phyilites, Schists, pelitic gneisses. Metapelites of the low P facies series (Buchan): Mottled slates, schists and pelitic hornfelses.

Practical 6. Quartz-feldspatic rocks. KNASH system. AKN Diagram. Nomenclature: semi-pelites, metapsamites and meta-granitoids. Main mineralogical changes.

Practical 7. Marbles and Calcsilicate rocks. CMS-HC system. CMS diagram. T - X CO2 diagrams: metamorphisms with internal or external buffering of reactions. Major mineralogical changes in pure marbles, dolomitic marbles and calcsilicate marbles along medium and low P gradients.

Methodology

Guided activities:

Theory Classes:

The main method will be classroom-based lectures. It is of the maximum interest that these become participative. The abstracts of the contents of presentations used by the teacher in the theoretical classes, as well as links to knowledge extension, will be provided to students through the Virtual Campus. Teachers consider as highly important that these abstracts of contents serve students to do a self first look and preparation of the corresponding theoretical session so that it allows the realization of more diversified activities when in the classroom, as partial explanations of only the most important or difficult aspects, resolution of main doubts or reinforcement exercises on the subject.

Practical Classes:

They consist of the study of a set of petrographic thin sections and hand samples of metamorphic rocks. The classes are structured in: a) Introductions to each practical subject. Those are provided to students, through the Virtual Campus, in varied formats. This introductions will contain photographic examples or useful links including graphic material for the practical sessions. It is considered as the maximum importance that these summaries of content serve to ensure that students make a pre-preparation in the corresponding practical session so that this allows for the utmost dedication to efective practice during the corresponding session. b) Students will work using standardised sheets of systematic observations on mineral assemblages and textures of thin sections, hand samples or photographic material, and they must do the corresponding annotations and outlines, which after must be incorporated into a practical dossier in ordered sequence. The presentation of this dossier may be requested to any student on several occasions during the semester, to check the progress of their work and to assignaqualification that will be considered in the evaluation. The students will have one or several solved examples in the CV, that they can use as references on the correct way to do descriptions. When the dossier is requested, teachers will assess on the one hand the progress (degree and overall quality of the descriptions from practice 1 to the current practice) and in greater detail the last descriptions (thin section, hand sample or both) done at the time of supervision.

Teachers may also require the presentation of exercises or problems related to the topics of each Theory or practice sessions, which can also be evaluated.

Field Practice:

There will be a one-day field trip (or alternative a virtual one, if required due to the sanitary situation) where it will be possible to observe outcrops of metamorphic rocks, the main types of lithologies and the main structures and textures related to metamorphic rocks. The practice will be carried out in an area to be determined (Axial zone of the Pyrenees, Costa Brava or coastal or pre-coastal mountain ranges on Montseny-Guilleries). Attendance is compulsory. At the discretion of the teacher, it may restrict (see details in the Evaluation section) the attendance to those students who have not participated enough on the subject (non-justified unattendance to 4 or more practicals or systematic non-assistance in the theoretical classes). The non-assistance to this fieldtrip if due to a major cause (generally medical) should be justified and documented to the teachers. The qualification related to the field trip will be done through a test on the content related to the explanations given during its development and to previous documentation provided. The test will be included in the second partial exam.

Supervised activities:

Tutorials: Students have the possibility of arranging an individual tutorial session with teachers via e-mail or through the communication tools of the virtual campus (a communications Forum will be established with the teachers).

Work in group (paper):

The teachers can establish a compulsory (or not) need to present a work in group on different aspects of the matter (aspects will be made public trough CV). This group work will be monitored, depending on the demand of the students who can arrange (e-mail) a tutorial with the teachers. If considered convenient, a short PPT presentation may be required (15') to check the evolution of the work. The final delivery may be in written format (will communicate the format and characteristics that must be taken), in electronic format or in both formats (will be communicated). It is also possible that teachers establish the obligatory use of a Wiki space in order to monitoring the work and evaluate the process of production as well as to estimate the differentiated contributions of each student in the group work.

Autonomous activity:

It is advisable for the student to devote a minimum of 80 hours of the semester to the autonomous activities of study, readings, bibliographic or virtual consultations, elaboration of the course work in group, self-assessments. To facilitate these tasks, students should use the Moodle Virtual Campus (CV) as the basis of information and orientation for study.

Virtual Campus (CV)-Moodle classroom:

This is fundamental to provide the students with new connections with the topics of study, many of the provided via the CV are different of those provided in classes of theory and practices, give the possibility to connect with the subject contents during autonomous work time, promote interactivity among the students and between them and the teachers through the use of the e-mail and forums discussion, give students the opportunityto access auto-qualification tools and give access to information on course events.

Annotation: Within the schedule set by the centre or degree programme, 15 minutes of one class will be reserved for students to evaluate their lecturers and their courses or modules through questionnaires.

Activities

Title	Hours	ECTS	Learning Outcomes
Type: Directed			
Field trip	7	0.28	8, 1, 6, 5

Practices	20	0.8	8, 1, 6, 2, 3, 5, 7, 9
Theory	24	0.96	8, 2, 4, 5
Type: Supervised			
Group work controls or tutorials (desk C2/162)	0	0	8, 1, 6, 7, 9
Type: Autonomous			
Study, reading, confection of grup work, autoevaluation through CV	86	3.44	8, 1, 6, 2, 3, 4, 5, 7, 9

Assessment

The learning outcomes are evaluated with CONTINUOUS ASSESSMENT (AC). The presentation to 35% of the AC implies that the qualification will not be "not presented". The non-presentation to a partial exam will compute as 0 in the calculation of the AC note. If the continuous assessment is not passed (AC mark not calculated due to ≤ 3 in any partial exam or calculated AC **<** 5 points, the student will have the obligation to present himself to the corresponding recovery exams (those in which he has obtained a note ≤ 3). If the qualification obtained in some exam of theory or practices recuperation still ≤ 3 then the maximum final grading will be of 4.5 (fail), regardless of the note that emerges from the final calculation.

CONTINUOUS ASSESSMENT (AC):

1. THEORY:

Qualification of two partial exams of theory. Both partial examns will consist of objective questions of multiple choice type and other kinds of short format/answer questions or interpretation comments on graphics related to the topic.

The weighting of each theoretical partial test is 20% of the continuous evaluation.

2. PRACTICALS:

a) qualification of two partial exams of practices. In the first test, the student must describe the mineralogical and textural aspects of a thin section and use the nomenclature related to a series of photographs or textural graphics. In the second test, the student must describe the mineralogical, textural aspects and name the type of rock of a thin section and a hand sample. In each the student must recognize the mineralogy (5 points to the first partial/3 points to the second partial), the textures, making a schema and placing the minerals and textures that are recognised (2 points to the first partial/3 points to the 2nd partial) and identify the type of rock according to the criteria ofglobal composition, textural and mineralogical content (2 points-only inthe second part). In addition, the first partial includes an extra examination containning figures (photos or schemes) on wich the student will have to identify the main textures (3 points only in the first partial). With regard to the hand sample, the description must be made (using the criteria that will be indicated throughout the course) and identify it (naming it according to the Standard IUGS nomenclature for Metamorphic Rocks) (2 points-only in the second part). The textural graphics made in exams of the thin sections and rocks must be presented with pencil in color. During the exams, you will only be able to consult your own dossiers elaborated prior to the exam, but in no case may you have any notes of any other type, such as books, Internet or collections of photographs. * Conditions not applicable in case of virtual examination.

The weighting of each practical partial test is 15% of the continuous evaluation.

b) Qualification of the dossier. The delivery of the dossier may be required to any student in one or more moments throughout the semester. Each student will be asked for the dossier at least 1 time. Each time the student will get a qualification and all these will be promediated at the end of the semester. The dossier's average grade will weigh 10%.

The Dossiers will contain the minimum descriptions detailed below:

Practice 1: Description and textural outline (drawing) of 1 thin section with granoblastic texture.

Practical Session 2: Description and textural outline of 1 thin section with reaction texture.

Practice 3: Description and textural outline of 1 thin section with deformational texture.

Practice 4: Description of the mineralogy, microstructure and classification of 2 thin sections of metabasites (to choose between amphibolite, granulite, eclogite or blueschist. 2 samples must be of different facies). 1 Description of a metabasite hand sample.

Practice 5: Description of the mineralogy, microstructure and classification of 2 thin sections of metapelites (schist, pelitic gneis, …). 1 Description of a metapelite hand sample (regional series or contact series).

Practice 6: Description of the mineralogy, microstructure and classification of 1 thin section and 1 hand sample of quartzfelsdpatic rock.

Practice 7: Description of mineralogy, microstructure and classification of 1 thin section of marbles/Calc-silicate. 1 Hand sample description of a marble or Calc-silicate rocks.

The student must achieve a minimum level of quality (at the discretion of the teacher) in the description schemes (examples will be provided) and in written descriptions.

The weighting of the dossier is 10% of the continuous evaluation.

c) Qualification of the assistance to the practices.

Will be assessed through a signature control at the end of the practice sessions.

The weighting of attendance mark is 5% of the continuous assessment.

Non-attendance to 4 or more practices will not allow the calculation of the AC mark. In this case, it will be obligatory to recover the two practical exams. The final mark in each partial exam will be in this case the average of marks obtained in the partial and in the recovery exam

3. EXERCISES RELATED TO THEORY and PRACTICES: These exercises/problems, with a guide for their resolution, can be sent by the teacher and delivered by the students via the file delivery (available within the virtual Campus) or in printed format, as indicated. The qualifications obtained will result in corrections to the qualification obtained in each partial exam of theory or practices.

4. FIELD:

Qualification of the test/field exam which will be incorporated to the second partial exam. *Weighting is 5% of continuous assessment.*

5. WORK IN GROUP:

Weighting: 10%. may be subdivided, in case there is oralpresentation or poster in:

a) grading of the contents of the work, following its presentation in writing format (format will be specified). *Weighting 5% of continuous assessment.*

b) Qualification of the oral or written presentation (presentation c. 15 '). In groups of students (the number of groups will be fixed). According to the number of students will be set if the intervention of all is necessary (in this case the note will be personalized) or should intervene only 1 or 2 representatives of the group (in which case the note will be group, the same by all members of the group). *Weighting 5% of continuous assessment.*

If the professors finnally decide not to propose this course work, the 10% corresponding to the grade would be assigned to the two partial exams, which would weigh 20% each, instead of 15%.

The FINAL GRADDING FOR CONTINUOUS Assessment (AC): This is obtained as a result of the following WEIGHTING formula: [mark in partial exam 1 theory (out of 10) x (0.20)] * * + [mark in partial exam 2 theory (out of 10) x (0.20)] * * + [mark in partial exam 1 practices (out of 10) x (0.15)] * * + [mark in partial exam 2 practices (out of 10) x (0.15)] * * + [mark in the Dossier (out of 10) x (0.10)] + [assistance to practices (out of 10) x (0.05)] + [field test mark (out of 10) x (0.05)] + [Work mark (out of 10) x (0.10)]. The minimum qualification for any of the theory or practices exams must be > 3 in order to be able to apply the above calculation and gave an AC mark. To pass the subject through continuous assessment it is necessary to obtain a minimum mark of 5 points in this calculation. The work contents will be evaluated on a written version which must be submitted when determined (unless otherwise indicated it will be in the date of the second partial and in any event before the recovery exams date). The marks obtained on exercises, on the work andonthe dossier will be definitive at the time of the calculation of the AC (so the referred marks will be considered not recoverable).

* * The qualifications obtained inthe theory and practice exams will be modified using those obtained in exercises done previously to each exam, if any. The notes of the partial exams on practices will convert to weigh 20% in case no coursework is finnally allocated.

RECOVERY EXAMS: Students who have not passed the subject trough continuous assessment (AC) or those who have passed for continuous assessment and who wish to have the option to get a higher qualification may present to the recovery exams. The format will be the same as in the previous partial exams. It is indispensable to be able to present to any recovery exam (students already passed by AC or with non-passed AC but having marks in any partial exam > 3) that they inform the teachers previously in the term that it will establish for the effect. Those who does not respect these terms will not be allowed to present to the recovery examinations). Those with marks ≤ 3 or not submitted in any exam of theory or practices, do not need to make this anouncement to teachers, as the presentation is obligatory for them.

If the final qualification obtained in some recovery exam of theory or practices is ≤ 3 then the maximum final qualification will be of 4.5 (non passed), regardless of the mark that emerges out of the calculation.

If you toke a recovery theory or practical exam to improve your note: If the grade obtained in the recovery is higher than the one obtained in the corresponding partial, the final mark will be taken into account in the final calculation. If the grade obtained in the recovery is lower than the one obtained in the corresponding partial, the arithmetic mean of the two marks will be considered.

For the above calculations any non-submitted is equivalent to the mark 0.

Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
1st Exam Practices (with corrections from rating related exercices, if there are some proposed)	15	2	0.08	1, 6, 5, 7
1st Exam Theory (with corrections from rating related exercices, if there are some proposed)	20	2	0.08	8, 1, 6, 4, 5, 7
2n Exam Theory (with corrections from rating related exercices, if there are some proposed)	20	2	0.08	8, 1, 6, 2, 4, 5, 7
2nd partial Exam Practices (with corrections from rating related exercices, if there are some proposed)	15	2	0.08	8, 1, 6, 2, 3, 5, 7
Assistance to Practices	5	0	0	8, 1, 6, 2, 3, 5, 7
Average grade of controls on the Practical Dossier	10	0	0	8, 1, 6, 3, 5, 7, 9
Test/Fied exam	5	1	0.04	8, 1, 6, 3,

				5, 7
Work in Group (if there are oral presentation or Poster 5% - written content 5%)	10	4	0.16	6, 7

Bibliography

Theory

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*Fettes, D. & Desmonds, J. (eds), (2007). Metamorphic Rocks: A classification and Glossary of Terms. Recomendations of the international Union of Geological Sciences Subcommission on the Systematics of Metamorphic Rocks. Cambridge U. Press.

Mason, R., (1990). *Petrology of the Metamorphic Rocks*. Second ed. Unwin Hyman. Londres.

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Spear, F.*S., (1993). Metamorphic Phase Equilibria and Pressure - Temperature - time Paths.* Mineralogical Society of America monograph.Whashington DC.

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Vernon, R.H., (2008), Principles of Metamorphic Petrology. Cambridge University Press.

*Winter, J.D., (2001). *An Introduction to Igneous and Metamorphic Petrology.* Prentice Hall.

Yardley, B.W.D. (1989). *An Introduction to Metamorphic Petrology.* Longman Earth Science Series. John Wiley & Sons, Inc. Nova York.

Practices

Barker, A.J., (1990*). Introduction to Metamorphic Textures and Microestructures*. Blackie & Son. Nova York.

*Nesse, W., (2004). Introduction to Optical Mineralogy. 3rd. Edition. Oxford University Press.

Spry, A., (1969). *Metamorphic Textures*. PergamonPress. Oxford.

*Vernon,R., (2004). *A practical Guide to Rock Microstructure.* Cambridge University Press.

*Yardley, B.W.D., Mackenzie, W.S. y Guilford, C.(1990). *Atlas of metamorphic rocks and their textures*. Longman Scientific & Technical.

* Preferent books to consult

web links

LES ROCHES METAMORPHIQUES : TEMOINS DE L'EVOLUTION THERMIQUE DE LA LITHOSPHERE DANS LE TEMPS ET DANS L'ESPACE

Classificació IUGS (SCMR) de les Roques Metamòrfiques

Igneous and Metamorphic Petrology class Materials. Winter, J. Whitman College.

Modelització analògica de Microestructures (University of Albany)

Atlas of Metamorphic Rocks, Minerals and Textures. Glazner and Ratajeski, University of N. Carolina

Thecourse's Virtual campus provides several additionallinks to electronic learning resources related to each of the topics in theory and practices

Software

No specific software is required.