

MONTANA

TECHNOLOGICAL UNIVERSITY

Ore Deposits

COURSE LEVEL OBJECTIVES

- **CO1** - List characteristics of each main ore deposits (**remember**)
- **CO2** - Sketch each ore deposit model (**apply**)
- **CO3** - Analyze a deformed ore deposit to distinguish between the initial model and secondary deformation (**analyze**)
- **CO4** - Assess the economic potential of a deposit early in the exploration process (**evaluate**)

COURSE FINAL PROJECT

Formal Proposal – Professional Report (simplified SEC/JORC/NI-43101 format) of a given ore deposit: recognize the type, the model, its geological setting, how deformation affects it, compare the resources to existing deposits and assess its economic potential (including ore grade and tonnage, what infrastructures are needed, permitting, investment VS return, identify processing pathways).

MODULE 1 OBJECTIVES

- **MO1** - List characteristics of magmatic Cu-Ni and magmatic PGE deposits (**remember**)
- **MO2** - Sketch a model of each magmatic Cu-Ni-PGE group (**apply**)
- **MO3** - Analyze a deformed magmatic Cu-Ni-PGE deposit to distinguish b/w model and deformation (**analyze**)
- **MO4** - Investigate magmatic Cu-Ni-PGE deposits in production (**analyze**)

MODULE 1 ACTIVITIES and ASSESSMENTS

ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Lecture (ppt?) of the 2 groups of magmatic Cu-Ni-PGE deposits• Reading of USGS' report• Exercise / interactive activity• Video of the Noril'sk deposit, Russia (lightboard)• Google Earth exploration of Duluth, Minnesota• Video of Stillwater deposit• Interactive map of the Bushveld deposit, SA• Lecture (lightboard) of deformation examples• Presentation of memos to instructor and Q&A	<ul style="list-style-type: none">• Quiz – multiple choice or T/F (MO1)• Sketch free-hand drawing (MO2)• Memos with figures (MO3 and MO4)

MODULE 2 OBJECTIVES

- **MO1** - List characteristics of Carbonatite REE-Nb-Ta deposits (**remember**)
- **MO2** - Sketch a model of a Carbonatite REE-Nb-Ta deposit (**apply**)
- **MO3** - Analyze a deformed Carbonatite REE-Nb-Ta deposit to distinguish b/w model and deformation (**analyze**)
- **MO4** - Investigate Carbonatite REE-Nb-Ta deposits in production (**analyze**)

MODULE 2 ACTIVITIES and ASSESSMENTS

ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none"> • Interactive lecture carbonate-rich melts geochemistry (Incl. video snippets) • Reading of Berndt, J. and Klemme, S., 2022. Origin of carbonatites—liquid immiscibility caught in the act. Nature Communications, 13(1), p.2892. • Exercise / interactive activity on Oldonyo Lengai volcano, Tanzania (the only active carbonatite and its place in plate tectonics) • Video of Mountain Pass deposit, California • Interactive map of the Palabora Complex near Phalaborwa, RSA • Lecture (lightboard) of deformation examples • Presentation of memos to instructor and Q&A • Discussion on environmental impacts 	<ul style="list-style-type: none"> • Quiz: Describe a typical Carbonatite REE-Nb-Ta deposit (multiple choice answers, self-graded) (MO 1) • Sketch a Carbonatite REE-Nb-Ta deposit (by hand, on white paper, scan and send to instructor) (MO 2) • Memo (1 page w/ figures): Recognize a deformed Carbonatite REE-Nb-Ta deposit and analyze the structural geology that affects the model. (MO 3) • Memo (1 page w/ figures): Evaluate what economic characteristics are required to bring a Carbonatite REE-Nb-Ta deposit into production by analyzing grades and tonnages of minor and majors case studies, as well as the investment/return that was involved. (MO 4)

MODULE 3 OBJECTIVES

- **MO1** - List characteristics of the 3 types of pegmatite deposits: mafic/ultramafic, syenite, and granitic (**remember**)
- **MO2** - Sketch a model of each pegmatite deposit group (**apply**)
- **MO3** - Analyze a deformed pegmatite deposit to distinguish b/w model and deformation (**analyze**)
- **MO4** - Investigate pegmatite deposits in production (**analyze**)

MODULE 3 ACTIVITIES and ASSESSMENTS

ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none"> • Interactive lecture on the three groups of pegmatites and their mineralogies (Incl. video snippets) • Reading of the "mafic-ultramafic Hamn intrusion, Northern Norway" article and questionnaire? • Google Earth exploration of Pegmatite Peak (syenite), Bearpaw Mts, Montana • Exercise / interactive activity on "LCT" vs "NYF" (granitic) pegmatites • Video of Black Hills pegmatite deposits, South Dakota • Interactive map of the Lithium pegmatites of the Carolina Tin-Spodumene Belt • Lecture (lightboard) of deformation examples • Presentation of memos to instructor and Q&A • Discussion on environmental impacts 	<ul style="list-style-type: none"> • Quiz: Describe the 3 types of pegmatite deposits (multiple choice answers, self-graded) (MO 1) • Sketch a Pegmatite Li-Be deposit (by hand, on white paper, scan and send to instructor) (MO 2) • Memo (1 page w/ figures): Recognize a deformed pegmatite deposit and analyze the structural geology that affects the model. (MO 3) • Memo (1 page w/ figures): Evaluate what economic characteristics are required to bring a pegmatite deposit into production by analyzing grades and tonnages of minor and majors case studies, as well as the investment/return that was involved. (MO 4)

MODULE 4 OBJECTIVES

- **MO1** - List characteristics of the five classes of porphyries based on the dominant element: Au, Cu, Mo, Sn, W (**remember**)
- **MO2** - Sketch a model of a porphyry deposit (**apply**)
- **MO3** - Analyze a deformed porphyry deposit to distinguish b/w model and deformation (**analyze**)
- **MO4** - Investigate porphyry deposits in production (**analyze**)

MODULE 4 ACTIVITIES and ASSESSMENTS

ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none"> • Interactive lecture on the three groups of pegmatites and their mineralogies (Incl. video snippets) • Reading of the "mafic-ultramafic Hamn intrusion, Northern Norway" article and questionnaire. • Google Earth exploration of Pegmatite Peak (syenite), Bearpaw Mts, Montana • Exercise / interactive activity on "LCT" vs "NYF" (granitic) pegmatites • Video of Black Hills pegmatite deposits, South Dakota • Interactive map of the Lithium pegmatites of the Carolina Tin-Spodumene Belt • Lecture (lightboard) of deformation examples • Presentation of memos to instructor and Q&A • Discussion on environmental impacts 	<ul style="list-style-type: none"> • Quiz: Describe the basic characteristics of porphyry deposits formation and the particularities that make them enriched in a specific element (Au, Cu, Mo, Sn, W), as well as their usual alteration envelopes (multiple choice answers, self-graded) (MO 1) • Sketch a porphyry deposit (by hand, on white paper, scan and send to instructor) (MO 2) • Memo (1 page w/ figures): Recognize a deformed porphyry deposit and analyze the structural geology that affects the model. (MO 3) • Memo (1 page w/ figures): Evaluate what economic characteristics are required to bring a porphyry deposit into production by analyzing grades and tonnages of minor and majors case studies, as well as the investment/return that was

	involved. (MO 4)
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MODULE 5 OBJECTIVES
<ul style="list-style-type: none"> • MO1 - List characteristics of the two types of skarns (prograde, retrograde) and of Carbonate Replacement Deposits, as well as the relationship between them (remember) • MO2 - Sketch a model of each skarn and CRDs (apply) • MO3 - Analyze a deformed skarn and CRD system to distinguish b/w model and deformation (analyze) • MO4 - Investigate skarns and CRDs in production (analyze)

MODULE 5 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none"> • Interactive lecture on skarns and CRDs incl. their mineralogies and relationship (Incl. video snippets) • Reading of the "Biro et al, 2024. Recsk Porphyry-Mineralized Complex, Hungary" article and questionnaire? • Google Earth exploration of Hecla Pb-Ag-Zn skarn, MT • Exercise / interactive activity (match) on elements VS their deposit (skarn vs CRDs) • Video of Elkorn, MT, Au-Bi deposit • Interactive map of the Calvert Mine W skarn • Lecture (lightboard) of deformation examples • Presentation of memos to instructor and Q&A • Discussion on environmental impacts 	<ul style="list-style-type: none"> • Quiz: Describe skarns (prograde, retrograde) and carbonate replacement deposits and their relationship (multiple choice answers, self-graded) (MO 1) • Sketch a prograde skarn, a retrograde skarn, and a CRD (by hand, on white paper, scan and send to instructor) (MO 2) • Memo (1 page w/ figures): Recognize a deformed skarn/CRD system and analyze the structural geology that affects the model. (MO 3) • Memo (1 page w/ figures): Evaluate what economic characteristics are required to bring a skarn deposit and a CRD into production by analyzing grades and tonnages of minor and majors case studies, as well as the investment/return that

	was involved. (MO 4)
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MODULE 6 OBJECTIVES
<ul style="list-style-type: none"> • MO1 - List characteristics of the two types of epithermal gold deposits: High sulfidation (HS) and low sulfidation (LS) (remember) • MO2 - Sketch a model of each skarn and CRDs (apply) • MO3 - Analyze a deformed epithermal gold deposit to distinguish b/w model and deformation (analyze) • MO4 - Investigate epithermal gold deposits in production (analyze)

MODULE 6 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none"> • Interactive lecture on Hs and LS epithermal gold deposits (Incl. video snippets) • Reading of the USGS' "Descriptive models for epithermal gold-silver deposits" article and questionnaire? • Google Earth exploration of Yanacocha, Peru (HS) • Exercise / interactive activity (match) on alterations around epithermal Au deposits • Video of Ore Deposits Hub 019: Magmatic–hydrothermal systems and the formation of epithermal deposits – Jeffrey Hedenquist (1 hour) • Interactive maps of the Summitville, CO (HS) and McLaughlin, CA (LS) • Lecture (lightboard) of deformation examples • Presentation of memos to instructor and Q&A • Discussion on environmental impacts 	<ul style="list-style-type: none"> • Quiz: Describe the two types of epithermal gold deposits (High sulfidation, low sulfidation) (multiple choice answers, self-graded) (MO 1) • Sketch a model of a high sulfidation and of a low sulfidation epithermal gold deposit (by hand, on white paper, scan and send to instructor) (MO 2) • Memo (1 page w/ figures): Recognize a deformed epithermal gold deposit and analyze the structural geology that affects the model. (MO 3) • Memo (1 page w/ figures): Evaluate what economic characteristics are required to bring epithermal gold deposits

	<p>into production by analyzing grades and tonnages of minor and majors case studies, as well as the investment/return that was involved.</p> <p>(MO 4)</p>
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MODULE 7 OBJECTIVES
<ul style="list-style-type: none"> • MO1 - List characteristics of orogenic gold deposits (remember) • MO2 - Sketch a model of an orogenic gold deposit (apply) • MO3 - Analyze a deformed orogenic gold deposit to distinguish b/w model and deformation (analyze) • MO4 - Investigate orogenic gold deposits in production (analyze)

MODULE 7 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none"> • Lecture 	<ul style="list-style-type: none"> • Quiz

MODULE 7 OBJECTIVES
<ul style="list-style-type: none"> • MO1 - List characteristics of orogenic gold deposits (remember) • MO2 - Sketch a model of an orogenic gold deposit (apply) • MO3 - Analyze a deformed orogenic gold deposit to distinguish b/w model and deformation (analyze) • MO4 - Investigate orogenic gold deposits in production (analyze)

MODULE 7 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS

- Interactive lecture on orogenic gold deposits and their tectonic environment (Incl. video snippets)
- Reading of "Nassi et al, 2022, Formation of orogenic gold deposits" article and questionnaire.
- Google Earth exploration of Yilgarn craton, Australia
- Exercise / interactive activity (match) on Faults and veins (tectonic context for precipitation of orogenic gold).
- Video of Homestake Mine, SD
- Interactive maps of the Timmons-Val d'Or greenstone belt, CA
- Lecture (lightboard) of deformation examples
- Presentation of memos to instructor and Q&A
- Discussion on environmental impacts

- Quiz

MODULE 8 OBJECTIVES	
<ul style="list-style-type: none">• MO1 - List	

MODULE 8 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Interactive	<ul style="list-style-type: none">• Quiz:

MODULE 9 OBJECTIVES	
<ul style="list-style-type: none">• MO1 - List	

MODULE 9 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Lecture	<ul style="list-style-type: none">• Quiz

MODULE 10 OBJECTIVES	
<ul style="list-style-type: none">• MO1 - List	

MODULE 10 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Interactive	<ul style="list-style-type: none">• Quiz:

MODULE 11 OBJECTIVES
<ul style="list-style-type: none">• MO1 - List

MODULE 11 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Lecture	<ul style="list-style-type: none">• Quiz

MODULE 12 OBJECTIVES	
<ul style="list-style-type: none">• MO1 - List	

MODULE 12 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Interactive	<ul style="list-style-type: none">• Quiz:

MODULE 13 OBJECTIVES	
<ul style="list-style-type: none">• MO1 - List	

MODULE 13 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Lecture	<ul style="list-style-type: none">• Quiz

MODULE 14 OBJECTIVES	
<ul style="list-style-type: none">• MO1 - List	

MODULE 14 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Interactive	<ul style="list-style-type: none">• Quiz:

MODULE 15 OBJECTIVES	
<ul style="list-style-type: none">• MO1 - List	

MODULE 15 ACTIVITIES and ASSESSMENTS	
ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Lecture	<ul style="list-style-type: none">• Quiz

MODULE 16 OBJECTIVES

- **MO1** - List

MODULE 16 ACTIVITIES and ASSESSMENTS

ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Interactive	<ul style="list-style-type: none">• Quiz:

MODULE 17 OBJECTIVES

- **MO1** - List

MODULE 17 ACTIVITIES and ASSESSMENTS

ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Lecture	<ul style="list-style-type: none">• Quiz

MODULE 18 OBJECTIVES

- **MO1** - List

MODULE 18 ACTIVITIES and ASSESSMENTS

ACTIVITIES	ASSESSMENTS
<ul style="list-style-type: none">• Interactive	<ul style="list-style-type: none">• Quiz: