**MINERAL DEPOSITS 51-322/522**
**SPRING 2008 SYLLABUS**
**3 CREDITS**

**INSTRUCTOR:** Dr. George J. Hudak
Office: 211 Harrington Hall
Phone: 424-4463
e-mail: hudak@uwosh.edu

**OFFICE HOURS**

| | |
|---|---|
| Monday | 11:30-12:30 |
| Wednesday | 11:30-1:40 |
| Friday | 11:30-12:30 |

**TEXTBOOKS:** Moon, C. J., Wateley, K. G., Evans, A. M., 2006, Introduction to Mineral Exploration, 2nd Edition: Blackwell Publishing, Malden, MA, 481 p. (ISBN-13: 978-1-4051-1317-5)

Hedenquist, J. W., Thompson, J. F. H., Goldfarb, R. J., and Richards, J. P., (eds.), 2005, Economic Geology 100th Anniversary Volume, 1905-2005: Society of Economic Geologists, Inc., Littleton, CO, 1136 p. (ISBN: 978-1-887483-01-8)

**SOFTWARE:** Dyar, M. D., 2005, Hands on Mineral Identification: TASA Graphic Arts Inc., version 1.1.

**ADDITIONAL READINGS** Many additional readings will be required (some recommended) during the semester. Many of these will be available from the black binder in Harrington 216 labeled "Mineral Deposits Readings". You may temporarily take the papers out of the binder to copy them. RETURN THEM IMMEDIATELY TO THE BINDER. Treat the papers in the binder with care, and do not write on them. Assigned readings are listed in the "Topical Outline" below, with suggested readings according to topic listed in the "Additional Readings" (also below).

**WEB RESOURCES:** There is a Desire to Learn (D2L) site set up for this course. Consult it on a daily basis for information regarding the course.

**COURSE POLICIES:**

***Schedule:*** Lecture: 10:20 – 11:20 MWF

***Attendance:*** Your regular attendance and note-taking will have a significant effect on your grade. It is in your best interest to attend each lecture and lab. As noted in the section titled "Total Points" below, class participation is worth 100 points (10% of your grade).

***Course Summary*** Mineral deposits geology (also known as Economic Geology) is one of the most fascinating fields in geology. This discipline in geology requires you to use *all* the tools you have acquired during your geological education, including mineralogy, lithology, stratigraphy, structural geology, geochemistry, geophysics, and particularly hand sample/field identification skills. Mineral deposits geology is a very process-oriented science – we will evaluate various types of data (field, chemical, mineralogical, geophysical, etc.) and incorporate our findings into developing models for how various types of mineral deposits form. One of the goals of studying mineral deposits is to determine the various field, mineralogical, petrological, structural, geochemical, and geophysical aspects of various types of ores. These detailed examinations are also essential for developing ideas and genetic models that will help us to more effectively and efficiently discover more mineral deposits, and are essential when mine engineers are developing mine plans. *At the present time, the minerals industry is in a "boom" period, largely due to the increased demand for metals by rapidly developing Asian countries (in particular, China and India). In fact, the need for natural resources has never been greater. This is good for all of you, as the demand for well-trained, field-oriented exploration geologists is also increasing.*

In recent years, the detailed evaluations of ore deposits carried out by economic geologists have also been useful in developing mining methods that are less deleterious to the environment than those employed previously. Such data have also been used to solve a number of serious environmental problems associated with old, abandoned mines. Many environmental solutions are essentially applied economic geology.

In this course, you will learn about a wide variety of mineral deposits types (see attached Topical Outline). You will do this through a combination of attending lectures, completing "lab-like" exercises, reading textbooks, journal articles, and field trip guidebooks, and attending a three-and-one-half day-long field trip to see precious metal and base metal prospects in northeastern Minnesota.

***Exams / Assignments:*** There will be <u>two take-home exams</u> on the lecture materials *(combined worth a total of 300 points).* <u>Exam 1</u> will cover the materials associated with the tools of the economic geologist (mapping, geochemistry, geophysics, etc.), igneous ore-forming processes, magmatic deposits, diamond deposits and kimberlite-hosted base- and precous metal deposits. *<u>Exam 2</u>* will cover hydrothermal processes, pluton-associated hydrothermal deposits, epithermal deposits, volcanic associated hydrothermal massive sulfide deposits, iron formations, and lode gold deposits . ***<u>All take home exams are to be done INDEPENDENTLY, otherwise you will not be given credit for the exam</u>*** (the rules are the same that govern the way many mining and mineral exploration companies work….if you are found to be discussing projects with people from other companies, you will be fired).

This course will be a combination of traditional lectures (generally on Mondays and Wednesdays) coupled with seminar-like days (where you run the course) and lab-like days (both of these will generally be on Fridays) in which we will look at minerals, rocks, or geochemical/geophysical data. There will several assignments associated with these "hands-on" days (things such as mineral and rock identification, logging drill core, evaluating geochemical data, and of course, looking at suites of rocks from various types of ore deposits).

Prior to the seminar days, I will assign a paper(s) or chapter(s) to read. If these days are to be successful learning experiences, you must read the paper(s) or chapter(s) prior to coming to class. *If it appears to me that the class (as a group) is not doing the assigned reading, I will assign short summary papers to be handed in <u>at the beginning of the seminar day</u> to make sure you have done your work.*

*<u>Expect three assignments worth 100 points each</u>.* These assignments will include exploration diamond drill core logging, mass-balance analysis of alteration and mineralization processes, and lithogeochemical evaluations of hydrothermal alteration zones.

*<u>There will also be two mineral and rock identification exams (100 points each) given during the semester.</u>* The first exam (given the end of the second week of the semester) will evaluate your retention of the minerals and rocks you learned during your Mineralogy and Lithology courses. The second (final) exam will evaluate your knowledge of the rocks and minerals (and associated ore deposits) that we will be discussing in class, as well as rocks and minerals learned in your Mineralogy and Lithology courses. The dates for these exams are listed on the "Topical Outline" below.

In addition to our regularly scheduled class, *<u>we will also be taking a three-and-one-half day-long field trip between May 1 and May 30</u>*. We will leave during the early evening of Thursday, May 1, and drive to a location near Duluth, Minnesota (about a six hour drive) and camp. On Friday we will wake up early (e.g. on the road by 7:30am) and spend the day investigating some key rock locations in the Duluth and Eveleth areas, then drive north to Soudan State Park, where we will go underground to look at a historical iron mine and a state-of-the-art physics lab (both ~2700 feet underground). We will camp that evening at Bearhead Lake State Park, which is located between Soudan and Ely, Minnesota. On Saturday day we will wake up early again, and look at Neoarchean iron formations, synvolcanic intrusions, submarine mafic and felsic metavolcanic rocks, and associated alteration zones and base metal mineralization within the Lower Member of the Ely Greenstone Formation. After lunch on a spectacular outcrop that illustrates three nearly perfectly preserved basalt sheet/pillow lava flows, we head over to the Mud Creek Road, and look at felsic volcaniclastic rocks and shear-zone type (lode) gold mineralization. On Sunday we will break camp early, eat a BIG breakfast in Ely, Minnesota, and then investigate disseminated Cu-Ni-PGE mineralization in the Proterozioc Duluth Gabbro, look at Keweenawan volcanic and sedimentary rocks along the western shoreline of Lake Superior and in Duluth, and then drive back to Oshkosh. _During the field trip, you will keep a field book which will be handed in and graded (100 points)._ More details of the trip and its costs will be provided later in the semester.

***Total Points:*** A summary of the total points possible in this course, based on the materials covered in the previous section of this syllabus, is summarized below:

| | | *Points* |
|---|---|---|
| Lecture Exams | 2 exams (150 points each) | 300 |
| Mineral/Rock ID Exams | 2 exams (100 points each) | 200 |
| "Hands-on Day" Projects | 3 projects (100 points each) | 300 |
| Class Participation | 100 points (given at end of semester) | 100 |
| Field Trip | Field Notebook | 100 |
| | *Total* | *1000* |

***Tray Reports***: _Oral tray reports_ can be completed during the course of the semester. Tray reports consist of individual efforts identifying unknown mineral and/or rock samples. _The tray reports essentially provide you with an opportunity to obtain a limited number of additional points in the course. There will be a limit of 8 tray reports per person (160 points) during the semester, so to perform well, lab exams, lecture exams, and homework will be extremely important!_ There will be a sliding scale in terms of the points available for each tray report. The following sliding scale will be used:

| | |
|---|---|
| Tray Reports 1, 2, and 3 | 15 points each |
| Tray Reports 4 and 5 | 20 points each |
| Tray Reports 6, 7, 8 | 25 points each |

The purpose of the sliding scale is to emphasize the importance of understanding and applying the materials covered in the lecture and lab parts of this course. The more of these you complete, the more points the tray reports are worth! ***You must successfully complete at least one tray report during the semester to pass the course (there will be absolutely no exceptions).***

***Grades:*** Your grade is based on your *total points* earned in the course. As you can see from the list above, the lecture materials (lecture exams 1, 2, and 3) hold the same amount of weight as hands-on rock and mineral-associated assignments (the "hands-on day projects, the mineral/rock ID exams, and the field trip). A tentative scale for grading is listed below:

| Grade | Percentage |
|---|---|
| A | 90% - 100% |
| AB | 85% – 89.9% |
| B | 80% - 84.9% |
| BC | 75% - 79.9% |
| C | 70% - 74.9% |
| CD | 65% – 69.9% |
| D | 60% – 64.9% |
| F | <60% |

**MINERAL DEPOSITS 51-322/522**
**Topical Outline 2006**

| ***Week of*** | ***Lecture Topics*** | ***Seminal/"Lab" Topics*** |
|---|---|---|
| **Feb. 4** | Introduction; The Tools of the Economic Geologist (Mapping/Petrography/Geochemistry/Geophysics/ Phase Diagrams) | Geophysics |
| **Feb. 11** | Magmatic Processes/ Magmatic Deposits (Magmatic Cr, Ti, Cu, Ni, PGE) | ***Mineral/Rock ID Exam/*** |
| **Feb. 18** | Magmatic Deposits / Diamonds (Magmatic Cu, Ni, PGE/ Kimberlite & Lamprophyres) | Magmatic Deposits |
| **Feb. 25** | Volcanic-Hosted Cu-Ni-PGE (Komatiite-hosted Deposits) | *Core Logging* |
| | ***FIRST MID-SEMESTER EXAM, DUE FRIDAY, FEBRUARY 29*** | |
| **March 3** | Pluton-Associated Hydrothermal Deposits (Porphyry Copper, Gold, Molybdenum, Epithermal Systems) | Porphyry Deposits |
| **March 10** | Volcanic Associated Hydrothermal Deposits (Epithermal Systems) | Epithermal Deposits |
| **March 17** | ***Spring Break*** | |
| **March 24** | Volcanic-Associated Hydrothermal Deposits (Epithermal / VMS Deposits) | *Isocon Evaluation* |
| **March 31** | Volcanic-Associated Hydrothermal Deposits (VMS Deposits) | VMS Chemical Model |
| **April 7** | Volcanic-Associated Hydrothermal Deposits (VMS and Gold-rich VMS Deposits) | *VMS Core/ Box Plot* |
| **April 14** | Volcanic-Sedimentary Associated Hydrothermal Deposits (Iron Formations/SEDEX) | Iron Formation |
| **April 21** | Structurally Controlled Precious Metal Deposits (Shear Zone (Lode) Gold) | Lode Gold |
| | ***SECOND MID-SEMESTER EXAM, DUE MONDAY, APRIL 21*** | |
| **April 28** | Carbonate-Associated Disseminated Gold Deposits (Carlin-type Gold) | ***Mineral/Rock ID Final Exam*** |
| | ***Field Trip To Northeastern Minnesota, May 1 – May 4 (more details later)*** | |
| May 5 | *No Class* - ILSG 54$^{nd}$ Annual Meeting (Marquette, MI | |
| May 12 | *No Class* – Precambrian Research Center Short Course on Volcanic Rocks and Mineral Depostis | |

## Required* and Optional** Readings

### ***Introduction: Tools of the Economic Geologist***

Moon, C. J., Whateley, M. K. G., and Evans, A. M., 2006, Chapters 1*, 2*, 7* (Chapter 7 will be discussed on Friday, February 8)

Robb, L., 2005. Introduction to Ore-Forming Processes: Introduction, pages 1-15**.

Robb, L., 2005. Introduction to Ore-Forming Processes: Ore Deposits in a Global Tectonic Setting, p. 311-344.**

### ***Magmatic Processes***

Raymond, L. A., 2002. Petrology: The Study of Igneous, Sedimentary, & Metamorphic Rocks: McGraw Hill, p. 161-192*.

Robb, L., 2005. Introduction to Ore-Forming Processes: Igneous Ore-forming Processes, p. 19-74*.

### ***Magmatic Deposits***

Barnes, S. J., and Lightfoot, P. C., 2005. Formation of magmatic nickel sulfide ore deposits and processes affecting their copper and platinum group element contents: Economic Geology 100$^{th}$ Anniversary Volume, p. 179-213*.

Cawthorn, R. G., Barnes, S. J., Ballhous, C., and Malitch, K. N., 2005. Platinum group element, chromium, and vanadium deposits in mafic and ultramafic rocks: Economic Geology 100$^{th}$ Anniversary Volume, p. 215-249.*

Eckstrand, O. R., 1996, 27.1 Nickel-copper sulfide: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 584-605**.

Duke, J. M., 1996, 28. Mafic-ultramafic hosted chromite: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 615-624**.

### ***Diamonds***

Gurney, J. J., Helmstaedt, H. H., le Roex, A. P., Nowicki, T. E., Richardson, S. H., and Westerlund, K. J., 2005, Diamonds: crustal distribution and formation processes in time and space and an integrated deposit model: Economic Geology 100$^{th}$ Anniversary Volume, p. 143-178.*

Moon, C. J., Whateley, M. K. G., and Evans, A. M., 2006, Chapter 17.*

Kjarstrand, B. A., 25. Primary Diamond Deposits: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 559-572**.

### ***Pluton-Associated Hydrothermal Deposits (Porphyry Systems)***

Seedorf, E., Dilles, J. H., Proffett, J. M., Einaudi, M. T., Zurcher, L., Stavast, W. J. A., Johnson, D. A., and Barton, M. D., 2005. Porphyry deposits: characteristics and origin of hypogene features: Economic Geology 100$^{th}$ Anniversary Volume, p. 251-298*.

Gammons, C. H., and Williams-Jones, A. E., 1997. Chemical mobility of gold in the porphyry-epithermal environment: Economic Geology, v. 92, p. 45-59*. (To be discussed on Friday, March 7)

Robb, L., 2005. Introduction to Ore-Forming Processes: Magmatic-Hydrothermal Ore-Forming Processes, p. 75-126**.

Kirkham, R. V., and Sinclair, W. D., 1996. 19. Porphyry copper, gold, molybdenum, tungsten, tin, silver: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 421-446**.

***Subaerial Volcanic-Associated Hydrothermal Deposits (Epithermal Systems)***

Simmons, S. F., White, N. C., John, D. A., 2005. Geological characteristics of epithermal precious and base metal deposits: Economic Geology 100$^{th}$ Anniversary Volume, p. 485-522.*

White, N. C., and Hedenquist, J. W., 1995. Epithermal Gold Deposits: Styles, characteristics, and exploration: SEG Newsletter, Number 23, p. 1-13.*

Dube, B., Dunning, G., and Laziere, K., 1998. Geology of the Hope Brook mine, Newfoundland, Canada: A preserved late Proterozoic high-sulfidation epithermal gold deposit and its implications for exploration: Economic Geology, v. 93, p. 405-436.* (This will be the basis of the Isocon Exercise)

Robb, L., 2005. Introduction to Ore-Forming Processes: Hydrothermal Ore-forming Processes, p. 129-215.**

Taylor, B. E., 1996. 15.1 Epithermal gold deposits: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 329-350.**

White, N. C., and Hedenquist, J. W., 1990. Epithermal Environments and styles of mineralization: variations and their causes, and guidelines for exploration: Journal of Geochemical Exploration, v. 36, no. 1-3, p. 445-474.**

***Submarine Volcanic-Associated Hydrothermal Deposits (VMS) and Gold-Rich VMS***

Franklin, J. M., Gibson, H. L., Jonasson, I. R., and Galley, A. G., 2005. Volcanogenic massive sulfide deposits: Economic Geology 100$^{th}$ Anniversary Volume, p. 523-560.*

Gibson, H. L., Morton, R. L., and Hudak, G. J., 1999. Submarine volcanic processes, deposits, and environments favorable for the location of volcanic-associated massive sulfide deposits: *in* Barrie, C. T., and Hannington, M. D., 1999, Volcanic-Associated Massive Sulfide Deposits: Processes and Examples in Modern and Ancient Settings, Reviews in Economic Geology, v. 8, p. 13-51.*

Hannington, M. D., Poulsen, K. H., Thompson, J. F. H., and Sillitoe, R. H., 1999. Volcanogenic gold in the massive sulfide environment: Reviews in Economic Geology, v. 8, p. 325-356.*

Hudak, G. J., Morton, R. L., Franklin, J. M., and Peterson, D. M., 2003. Morphology, distribution, and estimated eruption volumes for intracaldera tuffs associated with volcanic-hosted massive sulfide deposits in the Archean Sturgeon Lake Caldera Complex, NW Ontario: American Geophysical Union Monograph 40, Explosive Subaqueous Volcanism, p. 345-360.**

Franklin, J. M., 1996. 6.3 Volcanic-associated massive sulphide base metals: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 158-183.**

Poulsen, K. H., and Hannington, M. D.,, 1996. 6.4 Volcanic-associated massive sulphide gold: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 183-196.**

Moon, C. J., Whateley, M. K. G., and Evans, A. M., 2006, Chapter 17.**

***Volcanic/Sedimentary Associated Hydrothermal Deposits - Iron Formations***

Clout, J. M. F., and Simonson, B. M., 2005. Precambrian iron formation and iron formation-hosted ore deposits: Economic Geology 100$^{th}$ Anniversary Volume, p. 643-679.*

Robb, L., 2005. Introduction to Ore-Forming Processes: Sedimentary Ore-Forming Processes, p. 246-287.**

Gross, G. A., 1996. 3. Stratiform Iron: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 41-73.**

***Structurally-Controlled Precious Metal Deposits (Shear Zone (Lode) Gold)***

Goldfarb, R. J., Baker, T., Dube, B., Groves, D. I., Hart, C. J. R., and Gosselin, P., 2005. Distribution, character, and genesis of gold deposits in metamorphic terranes:

Kerswell, J. A., 1996. 15.3 Iron-formation-hosted stratabound gold: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 367-382.**

Poulsen, K. H., 1996a. 15. Lode Gold: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 323-328.**

Poulsen, K. H., 1996b. 15.4 Disseminated and replacement gold: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 383-392.**

Robert, F., 1996. 15.2 Quartz-carbonate vein gold: *in* Geology of Canadian Mineral Deposit Types, (ed.) O. R. Eckstrand, W. D. Sinclair, and R. I. Thorpe: Geological Survey of Canada, Geology of Canada, no. 8, p. 350-366.**

***Carbonate-Associated Disseminated Gold Deposits***

Cline, J. S., Hofstra, A. H., Muntean, J. L., Tosdale, R. M., and Hickey, K. A., 2005. Carlin-type gold deposits in Nevada: critical geological characteristics and viable models: Economic Geology $100^{th}$ Anniversary Volume, p. 451-484.*

Moon, C. J., Whateley, M. K. G., and Evans, A. M., 2006, Chapter 16.*

***Minnesota Field Trip***

Hudak, G. J., Heine, J., Jirsa, M., and Peterson, D. M., 2004. Field Trip 1: Volcanic stratigraphy, hydrothermal alteration, and VMS potential of the Lower Ely Greenstone, Fivemile Lake to Sixmile Lake area: in Severson, M. J. and Heinz, J., 2004, Institute on Lake Superior Geology, Proceedings Volume 50, Part 2 – Field Trip Guidebook, p. 1-44.*

Peterson, D. M., Jirsa, M. A., and Hudak, G. J., 2005. Field Trip 9: Architecture of an Archean greenstone belt: stratigraphy, structure, and mineralization: *in* Robinson, L., Minnesota Geological Survey Guidebook 21: Field Trip Guidebook for Selected Geology in Minnesota and Wisconsin: 2005 North Central GSA Meeting, p. 154-180.*

I will also indicate in class which of these readings (or which sections of these readings) you will need to study in more detail.

## Additional Readings Sources

### ***General Sources***


Bucher, K., and Frey, M., 1994. Petrogenesis of Metamorphic Rocks: Springer – Verlag, Berlin, 318 pages.

Evans, A. M., 1997. An Introduction to Economic Geology and its Environmental Impact: Blackwell Science, 364 pages

Guilbert, J. M., and Parks, C. F., 1986. The Geology of Ore Deposits: W. H. Freeman and Co., New York, 985 pages.

Kirkham, R. V. et al. 1995. Mineral Deposit Modeling: Geological Association of Canada Special Paper 40, 770 pages.

Lord, D., Etheridge, M., Willson, M., Hall, G., and Uttley, P., 2001. Measuring exploration success: an alternative to the discovery-cost-per-ounce method of quantifying exploration effectiveness: SEG Newsletter, no. 45, p. 1-16.

Misra, K. C., 2000. Understanding Mineral Deposits: Kluwer Academic Publishers, Dordrecht, 845 pages.

Miyashiro, A., 1994. Metamorphic Petrology: Oxford University Press, New York, 404 pages (specifically see Appendix 3 – Glossary of Metamophic Petrogenesis.

Phillips, G. N., Law, J. D. M., and Myers, R. E., 2001. Is the redox state of the Archean atmosphere constrained?: SEG Newsletter, no. 47, p. 1-18.

Richards, J. P., 2002. Sustainable development and the minerals industry: SEG Newsletter, no. 48, p. 1-12.

Rollinson, H., 1993. Using Geochemical Data: Evaluation, Presentation, Interpretation: Longman Scientific and Techical, New York, Chapter 7 “Using Stable Isotope Data”, pages 266-316.

Raymond, L. A., 1995. Petrology – The Study of Igneous, Sedimentary, and Metamorphic Rocks: Wm. C. Brown Publishing, Dubuque, IA, 742 pages.

Robert, R. G., and Sheahan, P. A., 1988. Ore Deposits Models: Geological Association of Canada Geoscience Canada Reprint Series 3, 200 pages.


### ***Introduction: Tools of the Economic Geologist***


Campbell, A. R., and Larson, P. B., 1998. Chapter 8 – Introduction to Stable Isotope Applications in Hydrothermal Systems: in Richards, J. P., and Larson, P. B., 1998, Techniques in Hydrothermal Ore Deposits Geology, Reviews in Economic Geology, v. 10, p. 173-194.

Hoover, D. B., Heran, W. D., and Hill, P. L., 1992. The Geophysical Expression of Selected Mineral Deposits Models: United States Department of the Interior, Geological Survey Open-File Report 92-557, 129 p.

Kyser, T. K. (ed.), 1987. Short Course in Stable Isotope Geochemistry of Low Temperature Fluids: Mineralogical Association of Canada Short Course Volume 13, 452 pages.

Lowe, C., Thomas, M. D., and Morris, W. A., 1999. Geophysics in Mineral Exploration - Fundamentals and Case Histories: Geological Association of Canada Short Course Notes Volume 14, 175 pages.

Richards, J. P., 2000. Lineaments revisited: SEG Newsletter, no. 42, p. 1-20.

Rollinson, H., 1993. Using Geochemical Data: Evaluation, Presentation, Interpretation: Longman Scientific and Techical, New York, 352 pages.

Thompson, A. J. B., Hauff, P. L., and Robitaille, A. J., 1999. Alteration mapping in exploration; application of short-wave infrared (SWIR) spectroscopy: SEG Newsletter, no. 39, p. 1-27.

Valley, J. W., Taylor, H. P., and O'Neil, J. R. (eds), 1986. Stable Isotopes in High Temperature Geological Processes: Reviews in Mineralogy Volume 16, 570 pages.

Wyman, D. A. (ed.), 1996. Trace Element Geochemistry of Volcanic Rocks - Applications for Massive Sulfide Exploration: Geological Association of Canada Short Course Notes Volume 12, 402 pages.

***Magmatic Processes***

Carrol, M. R., and Holloway, J. R. (eds), 1994. Volatiles in Magmas: Reviews in Mineralogy Volume 30, 517 pages.

Thomson, J. F. H., 1995. Magmas, Fluids, and Ore Deposits: Mineralogical Association of Canada Short Course Volume 23, 525 pages.

***Magmatic Deposits***

Arndt, N. T., Czamanske, G. K., Walker, R. J., Chauvel, C., and Fedorenko, V. A., 2003. Geochemistry and origin of the intrusive hosts of the Norli'sk-Talnakh Cu-Ni-PGE sulfide deposits: Economic Geology, v. 98, p. 495-515.

Naldrett, A. J. and Li, C. (eds.), 2000. A special issue on Voisey's Bay Ni-Co-Cu Deposit: Economic Geology, v. 95, no. 4, p. 673-928.

Theriault, R. D., Barnes, S. J., and Severson, M. J., 2000. Origin of Cu-Ni-PGE sulfide mineralization in the Partridge River Intrusion, Duluth Complex, Minnesota: Economic Geology, v. 95, no. 5, p. 929-943.

Wilde, A., Edwards, A., and Yakubchuk, A., 2003. Unconventional deposits of Pt and Pd: a review with implications for exploration: SEG Newsletter, no. 52, p. 1-18.

***Diamonds***

Bulanova, G. P., 1995. The formation of diamonds: Journal of Geochemical Exploration, v. 53, p. 1-24.

***Pluton-Associated Hydrothermal Deposits (Porphyry Systems)***

Barnes, H. L., 1975. Chapter 5 – "Hydrothermal Alteration" (pages 173-235), *in* Barnes, H. L., 1975, Geochemistry of Hydrothermal Ore Deposits: John Wiley and Sons, New York, 798 pages.

Barnes, H. L., 1997. Chapter 1 – Hydrothermal Ore Deposits – What We Do and Don't Know (pages 1-30), *in* Barnes, H. L., 1997, Geochemistry of Hydrothermal Ore Deposits, 3rd Edition: John Wiley and Sons, New York, 972 pages.

Chavez, W. X., 2000. Supergene oxidation of copper deposits: zoning and distribution of copper oxide minerals: SEG Newsletter, no. 41, p. 1-21.

Lang, J. R., Baker, T., Hart, C. J. R., and Mortenson, J. K., 2000. An exploration model for intrusion-related gold systems: SEG Newsletter, no. 40, p. 1-15.

Phillips, N., and Zhou, T., 1999. Gold-only deposits and Archean granite: SEG Newsletter, no. 37, p. 1-13.

***Subaerial Volcanic-Associated Hydrothermal Deposits (Epithermal Systems)***

Campbell, W. R., 1993. Research drilling into the "fluid reservoir" of the Creede epithermal vein system, San Juan Mountains, Colorada; a preliminary report: SEG Newsletter, no. 13, p. 1-16.

Elston, W. E., 1994. Siliceous volcanic centers as guides to mineral exploration; review and summary: Economic Geology, v. 89, p. 1662-1686.

Henly, R. W., and Hughes, G. O., 2000. Underground fumaroles: excess heat effects in vein formation: Economic Geology, v. 95, no. 3, p. 453-466.

Masterman, G. J., White, N. C., Wilson, C. J. L., and Pape, D., 2002. High sulfidation gold deposits in ancient volcanic terranes: insights from the mid-Paleozoic Peak Hill Deposit, NSW: SEG Newsletter, no. 51, p. 1-16.

***__Submarine Volcanic-Associated Hydrothermal Deposits (VMS) and Gold-Rich VMS__***

Cas, R. A. F., 1992. Submarine volcanism: eruption styles, products, and relevance to understanding the host-rock successions to volcanic-hosted massive sulfide deposits: Economic Geology, v. 87, p. 511-541.

DeMatties, T. A., 1994. Early Proterozoic volcanogenic massive sulfide deposits in Wisconsin: an overview: Economic Geology, v. 89, p. 1122-1151.

Dimroth, E., 1986. Depositional environments and tectonic settings of the cherty iron formations of the Canadian Shield: Journal of the Geological Society of India, v. 28, p. 239-250.

Doyle, M. G., and Huston, D. L., 1999. The sub-seafloor replacement origin of the Ordivician Highway-Reward volcanic associated massive sulfide deposit, Mount Windsor Subprovince, Australia: Economic Geology,v. 94, no. 6, p. 825-844.

Easton, R. M., and Johns, G. W., 1986. Volcanology and Mineral Exploration: The Application of Physical Volcanology and Facies Studies: Ontario Geological Survey Special Paper 129, p. 2-40.

Franklin, J. M., 1993. Volcanic-associated massive sulphide deposits, in Kirkham, R. V., Sinclair, W. D., Thorpe, R. I., and Duke, J. M, eds., Mineral Deposit Modeling: Geological Association of Canada, Special Paper 40, p. 315-334.

Gemmell, J. B. and Herrmann, W., (eds), 2001. A special issue devoted to alteration associated with volcanic-hosted massive sulfide deposits, and its exploration significance: Economic Geology, v. 96, no. 5, p. 909-1319.

Gibson, H. L., Watkinson, D. H., and Comba, C. D. A., 1983. Silicification: Hydrothermal alteration in an Archean geothermal system within the Amulet Rhyolite Formation, Noranda, Quebec; Economic Geology, v. 78, p. 954-971.

Gibson, H. L., Watkinson, D. H., and Comba, C. D. A., 1989. Subaqueous phreatomagmatic explosion breccias at Buttercup Hill, Noranda, Quebec: Canadian Journal of Earth Science, v. 26, p. 1428-1439.

Hannington, M. D., Jonasson, I. R., Herzig, P. M., and Peterson, S., 1995. Physical and chemical processes of seafloor mineralization at mid-ocean ridges; American Geophysical Union Monograph 91, p. 115-157.

Herzig, P. M., and Hannington, M. D., 1995. Polymetallic massive sulfides at the modern seafloor – a review: Ore Geology Reviews, v. 10, p. 95-115.

LaBerge, G. L. (ed.), 1996. Volcanogenic massive sulfide deposits of northern Wisconsin: A commemorative volume: Institute on Lake Superior Geology Proceedings, 42nd Annual Meeting, Cable, WI, v. 42, part 2, 179 pages.

Large, R. R., Gemmell, J. B., Paulick, H., and Huston, D., 2001. The alteration box plot: a simple approach to understanding the relationships between alteration mineralogy and lithogeochemistry associated with volcanic hosted massive sulfide deposits: Economic Geology, v. 96, p. 957-971.

Lydon, J. W., 1988. Ore Deposits Models #14 – Volcanogenic Massive Sulphide Deposits, Part 2, Genetic Models: Geoscience Canada, v. 15, no. 1, p. 43-65.

Morton, R. L., and Franklin, J. M., 1987. Two-fold classification of Archean volcanic-associated massive sulfide deposits: Economic Geology, v. 82, p. 1057-1063.

Ohmoto, H., 1996. Formation of volcanogenic massive sulfide deposits: the Kuroko perspective: Ore Geology Reviews, v. 10, p. 135-177.

Peterson, S., Herzig, P. M., Hannington, M.D., Jonasson, I. R., and Arribas, A., 2002. Submarine gold mineralization near Lihir Island, New Ireland Fore-Arc, Papua New Guinea: Economic Geology, v. 97, p. 1795-1813.

Saccocia, P. J., Ding, K., Berndt, M. E., Seewald, J. S., and Seyfried, W. E., Jr., 1994. Experimental and theoretical perspectives on crustal alteration at mid-ocean ridges: in Lentz, D. R., ed., Alteration and Alteration Processes associated with ore-forming systems: Geological Association of Canada Short Course Notes, v. 11, p. 403-431.

Santaguida, F., Gibson, H. L., and Watkinson, D. H., 1999. Hydrothermal alteration mineral assemblages associated with volcanogenic-hosted massive sulfide mineralization in the Noranda area, Quebec: Geological Association of Canada / Mineralogical Association of Canada Annual Meeting, Sudbury, Ontario, Canada, May 29-31, Field Trip Guidebook B8, 57 pages.

Sherlock, R. L., Roth, T., Spooner, E. T. C., and Bray, C. J., 1999. Origin of the Eskay Creek precious metal-rich volcanogenic massive sulfide deposit: fluid inclusion and stable isotope evidence.

Sillitoe, R. H., Hannington, M. D., and Thompson, J. F. H.,1996. High sulfidation deposits in the volcanogenic massive sulfide environment: Economic Geology, v. 91, p. 204-212.

Soriano, C. and Marti, J., 1999. Facies analysis of volcano-sedimentary successions hosting massive sulfide deposits in the Iberian Pyrite Belt, Spain: Economic Geology, v. 94, no. 6, p. 867-882.

***Volcanic/Sedimentary Associated Hydrothermal Deposits - Iron Formations***

Appel, P. W. U., and LaBerge, G., 1987. Precambrian Iron Formations: Theophrastus Publications, Athens, Greece.

Klein, C., 2005. Some Precambrian banded iron formations (BIF's) from around the world: their age, geological setting, mineralogy, metamorphism, geochemistry, and origins: American Mineralogist, v. 90, no. 10, p. 1473-1499.

***Sediment-Associated Hydrothermal Deposits (Sedex/Mississippi Valley-Type)***

Goodfellow, W.D., 2003. Key attributes of stratiform Zn-Pb-Ag deposits in sedimented continental rifts: application to mineral exploration: Crossroads of the Earth, Universite du Quebec a Chicoutimi, p. 49.

Leach, D. L., 2002. Mississippi valley-type lead-zinc deposits through Earth history: in Marsh, E., Goldfarb, R. J., and Warren, C., 2002, Global Exploration 2002: Integrated Methods for Discovery, p. 29-30.

***Structurally-Controlled Precious Metal Deposits (Shear Zone (Lode) Gold)***

Colvine, A. C., Fyon, J. A., Heather, K. B., Marmont, S., Smith, P. M., and Troop, D. G. (eds), 1988. Archean Lode Gold Deposits in Canada: Ontario Geological Survey Special Paper 139, 136 pages

***Minnesota Field Trip***

Minnesota Exploration Conference 1999 Proceedings – Lode Gold and Massive Sulfide Prospects in the Archean Western Vermilion District of Northeastern Minnesota, 30 pages.

***Carbonate-Associated Disseminated Gold Deposits (Carlin-Type Gold)***

Teal, L., and Jackson, M., 1997. Geological Overview of the Carlin Trend Gold Deposits and Descriptions of Recent Deep Discoveries: *in* Vikre, P., Thompson, T. B., Bettles, K., Christensen, O., and Parrat, R. (eds.), Carlin-Type Gold Deposits Field Conference, Society of Economic Geologists Guidebook Series Volume 28, p. 3-38.