Lecture 7, Appendix 1

Partition Coefficient Literature (this list is not complete!)

I. RECENT NATURAL SYSTEMS STUDIES

A. Phenocryst/Matrix

Norman et al., Trace element distribution coefficients for pyroxene, plagioclase and olivine in evolved tholeiite, etc., *Am. Min*., 9, 888-899, 2005.

B. Inter-mineral partitioning in upper mantle rocks

Lee, Harbart and Leeman, Extension of lattice strain theory to mineral/mineral REE partitioning: an approach for assessing equilibrium and developing internally consistent partition coefficients between olivine, orthopyroxene, clinopyroxene and basaltic melt, *GCA*, 71, 481-496, 2007.

II. EXPERIMENTAL STUDIES

A. Important Reviews:

1) Blundy and Wood, Partitioning of trace elements between crystals and melts, *EPSL*, 210, 383-397, 2003.
2) Wood and Blundy, Trace element partitioning under crustal and uppermost mantle conditions: the influences of ionic radius, cation charge, pressure and temperature, *Treatise On Geochemistry*, Volume 2, Chapter 9, pp 395-424, 2003 (available on MIT Library Web Site).
3) Jones, J.H., Experimental Trace Partitioning, in Rock Physics and Phase Relations, A Handbook of Geophysical Constants, AGU Reference Shelf 3, 73-104, 1995.

4) Green, T.H., Experimental studies of trace-element partitioning applicable to igneous petrogenesis, *Chem. Geol*., 117, 1-37, 1994. Note that Chem. Geol. 117 is a special 1994 issue devoted to "Trace Element Partitioning With Application to Magmatic Processes". (It contains 20 papers that are not itemized in the following lists).

5) McKay, G.A., Partitioning of Rare Earth Elements between major silicate minerals and basaltic melts, Reviews in Mineralogy, Vol. 21, *Mineral. Soc. Amer*., B.R. Lipin and G. McKay (eds.), 45-77, 1989.

B. Contributions from the <u>Wood-Blundy Group:</u>

1) Blundy and Wood, Crystal-chemical controls on the partitioning of Sr and Ba between plagioclase feldspar, silicate melts and hydrothermal solution, *Geochim. Cosmochim. Acta*, 55, 193-209, 1991.

2) Wood and Blundy, Prediction of crystal-melt partition coefficients from elastic moduli, *Nature*, 372, 452-454, 1994.

3) Wood and Blundy, The effect of cation charge on crystal-melt partitioning of trace elements, *EPSL*, 188, 59-71, 2001.

4) Brooker et al., The "zero charge" partitioning behavior of noble gases during mantle melting, *Nature*, 423, 738-741, 2003.

5) Heber, Brooker, Kelley and Wood, Crystal-melt partitioning of noble gases (He, Ne, Ar, Kr and Xe) for olivine and clinopyroxene, *Geochim. Cosmochim. Acta*, 71, 1041-1061, 2007.

6) McDade, Blundy and Wood, Trace element partitioning on the Tinaquillo lherzolite solidus at 1.5 Gpa, *Phys. Earth & Planet. Int*., 139, 129-147, 2003.

7) Wood, B.J. and Trigila, R., Experimental determination of aluminous clinopyroxene-melt partition coefficients for potassic liquids with application to the evolution of the RomanProvince magmas, *Chem. Geol*., 172, 213-223, 2001.

8) Hill, F., Wood, B.J., and Blundy, J.D., The effect of Ca-Tschermaks component on trace element partitioning between clinopyroxene and silicate melt, *Lithos*, 53, 203-215, 2000.

9) Blundy, J. and Dalton, J., Experimental comparison of trace element partitioning between clinopyroxene and melt in carbonate and silicate systems, and implications for mantle metasomatism, *CMP*, 139, 356-371, 2000.

C. Contributions from the Salters/Longhi Group:

1) Salters, Longhi, Bizimis, Near mantle solidus trace element partitioning at pressures up to 3.4 Gpa, *Geochem. Geophys. Geosystems* (electronic AGU journal) 10.1029/2001 GC 000148 (2002).

2) Salters and Longhi, Trace element partitioning during the initial stages of melting beneath mid-ocean ridges, *EPSL*, 166, 15-30, 1999.

D. The Henry's Law Problem

1) Drake, M.J. and Holloway, J.R., "Henry's Law behavior of Sm in a natural plagioclase/melt system: Importance of experimental procedure, *Geochim. Cosmochim. Acta*, 42, 678-684, 1982.

2) Drake, M.M. and Holloway, J.R., Partitioning of Ni between olivine and silicate melt: the 'Henry's Law Problem' re-examined, *Geochim. Cosmochim. Acta*, 45, 431-437, 1981.

3) Navrotsky, A., Thermodynamics of element partitioning: (1) Systematics of transition metals in crystalline and molten silicate and (2) Defect chemistry and the "Henry's Law Problem", *Geochim. Cosmochim. Acta*, 42, 887-901, 1978.

4) Harrison, W.J. and B.J. Wood, An experimental investigation of the partitioning of REE between garnet and liquid with reference to the role of defect equilibria, *Contrib. Mineral. Petrol.*, 72, 145-155, 1980.

5) Watson, E.B., Henry's Law behavior in simple system and magmas: Criteria for discerning concentration-dependent partition coefficients in nature, *Geochim. Cosmochim. Acta*, 49, 917-923, 1985.

6) Prowatke and Klemme, Rare earth element partitioning between titanite and silicate melts: Henry's Laws Revisited, *Geochim. Cosmochim. Acta*, 70, 4997-5012, 2006.

E. Beta-Track Mapping Procedure

1) Mysen, B., Seitz, M.G., Trace element partitioning determined by beta-track mapping: an experimental study using carbon and samarium as examples, *J. Geophys. Res*., 80, 2627-2635, 1974.

2) Mysen, B., Trace-element partitioning between garnet peridotite minerals and water-rich vapor: experimental data from 5 to 30 kbar, *Am. Miner*., 64, 272-287, 1979.

3) Mysen, B., Experimental determination of rare-earth element partitioning between hydrous silicate melt, amphibole and garnet peridotite minerals at

upper mantle pressures and temperatures, *Geochim. Cosmochim. Acta*, 42, 1253-1263, 1978.

4) Wendlandt, R.F. and Harrison, W.J., Rare earth partitioning between immiscible carbonate and silicate liquids and CO2 vapor: results and implication for the formation of light rare-earth enriched rocks.
5) Apted, M.J., and Boettcher, Partitioning of rare earth elements between garnet and andesite melt: an autoradiographic study of P-T-X effects, *Geochim. Cosmochim. Acta*, 45, 827-837, 1981.
6) Tingle, An evaluatuion of the Carbon-14 Beta track technique: Implications for solubilities and partition coefficients determined by beta track mapping, *Geochim. Cosmochim. Acta*. 51, 2479-2487, 1987.

III. SPECIFIC MINERALS

A. Clinopyroxene:

1) Wood and Blundy, A predictive model for rare earth element partitioning between clinopyroxene and anhydrous silicate melt, *Contrib. Mineral. Petrol*., 129, 166-181, 1997.
2) Lundstrom, Shaw, Ryerson, Williams and Gill, Crystal chemical control of clinopyroxene-melt partitioning in the Di-Ab-An system: implications for elemental fractionations in the depleted mantle, *Geochim. Cosmochim. Acta*, 62, 2849-2862, 1998.
3) Blundy, Robinson and Wood, Heavy REE are compatible in clinopyroxene on the spinel lherzolite solidus, *Earth Planet. Sci. Letts*., 160, 493-504, 1998.

4) Hill, F., Wood, B.J., and Blundy, J.D., The effect of Ca-Tschermaks component on trace element partitioning between clinopyroxene and silicate melt, *Lithos*, 53, 203-215, 2000.

5) Wood, B.J., and Trigila, R., Experimental determination of aluminous clinopyroxene-melt partition coefficients for potassic liquids with application to the evolution of the Roman Province potassic magmas, *Chem. Geol.* 172, 213-223, 2001.

6) Pertermann and Hirschmann, Trace element partitioning between vacancy-rich eclogitic clinopyroxene and silicate melt, *Amer. Mineral.*, 87, 1365-1376, 2002.

7) Schosnig and Hoffer, Compositional dependence of REE partitioning between diopside and melt at 1 atmosphere, *Contrib. Mineral. Petrol*., 133, 205-216, 1998.

8) Johnson, Experimental determination of partition coefficients for rare earth and high-field strength elements between clinopyroxene, garnet and basaltic melt at high pressures, *Contrib. Mineral. Petrol*., 133, 60-68, 1998.

9) Gaetani, G.A. and Grove, T.L., Partitioning of rare earth elements between clinopyroxene and silicate melt: crystal chemical controls, *Geochim. Cosmochim. Acta*, 59, 1951-1962, 1995.

10) Lundstrom et al., Compositional controls on the partitioning of U, Th, Ba, Pb, Sr and Zr between clinopyroxene and haplobasaltic melts: implications for uranium series disequilibria in basalts, *EPSL*, 128, 407-423, 1994.

11) Hauri, Wagner and Grove, Experimental and natural partitioning of Th, U, Pb and other trace elements between garnet, clinopyroxene and basaltic melts, *Chem. Geol*., 117, 149-166, 1994.

12) Hart, S.R. and Dunn, T., Experimental cpx/melt partitioning of 24 trace elements, *Contrib. Mineral. Petrol*., 113, 1-8, 1993.

B. Garnet:

1) Van Westrenen, Blundy and Wood, Crystal-chemistry controls on trace element partitioning between garnet and anhydrous silicate melt, *Amer. Min*. 84, 838-847, 1999.
2) Van Westrenen, Wood and Blundy, A predictive thermodynamic model of garnet-melt trace element partitioning, *Contrib. Mineral. Petrol*., 142, 219-234, 2001.
3) Klemme, Blundy and Wood, Experimental constraints on major and trace element partitioning during partial melting of eclogite, *Geochim. Cosmochim. Acta*, 66, 3109-3123, 2002.
4) Van Westrenen et al., HFSE/REE fractination during partial melting in the presence of garnet: Implications for identification of mantle heterogeneities, *Geochem. Geophys. Geosyst*. 2, 2000 GC000133.
5) Petermann, et al., Experimental determination of trace element partitioning between garnet and silica-rich liquid during anhydrous partial melting of MORB-like eclogite. *Geochem. Geophys. Geosystems*. doi:10.129/2003GC000638, 2004.
6) Elkins, Gaetani and Sims, Partitioning of U and Th during garnet pyroxenite partial melting? Constraints on the source of alkaline ocean island basalts, *EPSL*, 265, 207-286, 2008.

C. Olivine and Orthopyroxene:

1) Schwant and McKay, Rare earth element partition coefficients from enstatite/melt synthesis experiments, *GCA*, 62, 2845-2848, 1999.

2) Taura, Yurimoto, Kurita and Sueno, Pressure dependence on partition coefficients for trace elements between olivine and co-existing melts, *Phys. Chem. Minerals*, 25, 469-484, 1998.

3) Nielsen, R.L., Gallahan, W.E. and Newberger, F., Experimentally determined mineral-melt partition coefficients for Sc, Y and REE for olivine, orthopyroxene, pigeonite, magnetite and ilmenite, *Contrib. Mineral. Petrol*., 110, 488-499, 1992.

4) Beattie, P., Ford, C. and Russell, D., Partition coefficients of olivine-melt and orthopyroxene-melt systems, *Contrib. Mineral. Petrol.*, 109, 212-224, 1991.

5) Kennedy, A.K., Lofgren, G.E. and Wasserburg, G.J., An experimental study of trace element partitioning between olivine, orthopyroxene and melt in chondrites: equilibrium values and kinetic effects, *Earth Planet. Sci. Lett*., 115, 177-195, 1993.

6) McKay, G., Crystal/liquid partitioning of REE in basaltic systems: extreme fractionation of REE in olivine, *Geochim. Cosmochim. Acta*, 50, 68-79, 1986.

D. Plagioclase:

1) Bedard, Trace element partitioning in plagioclase, GCA, 70, 3717-3742, 2006.

2) Bindeman, Davis and Drake, Ion microprobe study of plagioclase-basalt partition experiments at natural concentration levels of trace elements, *Geochim. Cosmochim. Acta*, 62, 1175-1193, 1998.

3) Bindeman, I.N. and Davis, A.M., Trace element partitioning between plagioclase and melt: Investigation of dopant influence on partition behavior, *Geochim. Cosmochim. Acta*, 64, 2863-2878, 2000.

4) Vander Auwera, J., Longhi, J., and Duchesne, J.C., The effect of pressure on D_{Sc} (plag/melt) and D_{Cr} (opx/melt): Implications for anorthosite petrogenesis, *EPSL*, 178, 303-314, 2000.

5) Miller, Asimow, and Burnett, Determination of melt influence on divalent element partitioning between anorthite and CMAS melts, *Geochim. Cosmochim. Acta*, 70, 4258-4274, 2006.

E. Amphibole:

1) Hilyard, Nielsen, Beard, Patino-Douce and Blencoe, Experimental determination of the partitioning behavior of rare earth and high field strength elements between paragasitic amphibole and natural silicate melts, *Geochim. Cosmochim. Acta*, 64, 1103-1120, 2000.

2) Dalpe, C. and Baker, D.R., Experimental investigation of large-ion-lithophile-element-high-field-strength-element- and rare-earth-element-partitioning between calcic amphibole and basaltic melt: the effects of pressure and oxygen fugacity, *CMP*, 140, 233-250, 2000.

3) Botazzi, P., Tiepolo, M., Vannucci, R., Zanetti, A., Brumm, R., Foley, S.F. and Oberti, R., Distinct site preferences for heavy and light REE in amphibole and prediction of $^{Amph/L}D_{REE}$, *CMP*, 137, 36-45, 1999.

4) Oberti, R., Vanucci, R., Zanetti, A., Tiepolo, M. and Brumm, R.C., A crystal chemical re-evaluation of amphibole/melt and amphibole/clinopyroxene D_{Ti} values in petrogenetic studies, *Am. Mineral*., 85, 407-419, 2000.

5) Tiepolo, M., Vannucci, R., Oberti, R., Foley, S., Bottazzi, P. and Zanetti, A., Nb and Ta incorporation and fractionation in titanium pargasite and kaersutite: crystal-chemical constraints and implications for natural systems, *EPSL*, 176, 185-201, 2000.

6) Tiepolo, M., Vannucci, R., Bottazzi, P., Oberti, R., Zanetti, A. and Foley, S., Partitioning of rare earth elements, Y, Th, U and Pb between pargasite, kaersutite, and basanite to trachyte melts: Implications for percolated and veined mantle, *Geochemistry, Geophys., Geosystems*, paper number 2000GC000064.

7) Tiepolo, M., Bottazzi, P., Foley, S.F., Oberti, R., Vannucci, R. and Zanetti, A., Fractionation of Nb and Ta from Zr and Hf at mantle depths: the role of titanium pargasite and kaersutite, *Jour. Petrol.*, 42, 221-232, 2001.

8) Klein et al., Partitioning of high field strength and rare-earth elements between amphibole and quartz dioritic to tonalitic melts: an experimental study, *Chem. Geol*., 138, 257-271, 1997.

9) LaTourette et al., Trace element partitioning between amphibole, phlogopite and basanite melt, *EPSL*, 135, 13-30, 1995.

10) Brenan et al., Experimental determination of trace-element partitioning between paragasite and a synthetic hydrous andesite melt, *EPSL*, 135, 1-11, 1995.

11) Adam, J., Green, T.H., and Sie, S.H., Proton microprobe determined partitioning of Rs, Sr, Ba, Y, Zr, Nb and Ta between experimentally produced amphiboles and silicate melts with variable F content, *Chem. Geol*., 109, 29-49, 1993.

F. Micas: Phlogopite and Biotite:

1) Guo and Green, Experimental study of the partitioning between phlogopite and silicate liquid, *Lithos*, 93-96, 1990.

2) La Tourette, et al., Trace element partitioning between amphibole, phlogopite and basanite melt, *EPSL*, 135,13-30, 1995

3) Schmidt et al., Trace element partitioning between phlogopite, clinopyroxene and leucite lamproite melt, *Earth Planet. Sci. Letts*., 168, 287-299, 1999.

4) Melzer and Wunder, K-Rb-Cs partitioning between phlogopite and fluid: experiments and consequences for the LILE signatures of island arc basalts, *Lithos*, 59, 69-90, 2001.

5) Foley, Jackson, Fryer, Greenough and Jenner, Trace element partition coefficients for clinopyroxene and phlogopite in an alkaline lamprophyre from Newfoundland by LAM-ICP-MS, *GCA*, 60, 629-638, 1996.

6) Green, Blundy, Adam and Yaxley, SIMS determination of trace element partition coefficients between garnet, clinopyroxene and hydrous basaltic liquids of 2-87.5 Gpa and 1080-1200˚C (includes data for a phlogopite), *Lithos*, 53, 165-187, 2000.

7) Yang, P., and Rivers, T., Trace element partitioning between coexisting biotite and muscovite from metamorphic rocks, Western Labrador: structural, compositional and thermal controls, GCA, 64, 1451-1472, 2000.

G. Rutile:

1) Brenan et al., Rutile-aqueous fluid partitioning of Nb, Ta, Hf, Zr, U and Th: Implications for high field strength element depletions in island arc basalts, *EPSL*, 128, 327-339, 1994.

2) Stalder et al., Mineral aqueous fluid partitioning of trace elements at 900˚-1200˚C and 3.0-5.7 Gpa: New experimental data for garnet, clinopyroxene and rutile and implications for mantle metasomatism, *GCA*, 1781-1801, 1998.
3) Foley, Barth and Jenner, Rutile/melt partition coefficients for trace elements and an assessment of the influence of rutile on the trace element characteristics of subduction zone magmas, *GCA*, 64, 933-938, 2000.
4) Horng, W.S. and Hess, P.C., Partition coefficients of Nb and Ta between rutile and anhydrous haplogranite melts, *CMP*, 138, 176-185, 2000.
5) Schmidt, M.W., Dardon, A., Chazot, G. and Vannucci, R., The dependence of Nb and Ta rutile-melt partitioning on melt composition and Nb/Ta fractionation during subduction processes, *Chem. Geol*., 296, 415-432, 2004.
6) Schmidt et al., The dependence of Nb and Ta rutile-melt partitioning on melt composition and Nb/Ta fractionation during subduction processes, *EPSL*, 226, 415-432, 2004.
7) Xigong, Adam and Green, Rutile stability and rutile/melt HFSE partitioning during partial melting of hydrous basalts: implications for TTG genesis, *Chem. Geol*., 218, 339-359, 2005.
8) Klemme et al., Partitioning of trace elements between rutile and silicate melts; implications for subduction zones, *GCA*, 69, 2361-2371, 2005.

H. Titanite:

1) Tiepolo et al., Trace element incorporation in titanite: constraints from experimentally determined solid/liquid partition coefficients, *Chem. Geol*., 191, 105-119, 2002.

2) Prowatke and Klemme, Effect of melt composition on the partitioning of trace elements between titanite and silicate melt, *GCA*, 695-704, 2005.

3) Prowatke and Klemme, Rare earth partitioning between titanite and silicate melts: Henry's Law revisited, *Geochim. Cosmochim. Acta*, 70, 4997-5012, 2006.

I. Magnetite:

1) Nielsen and Beard, Magnetite-melt HFSE partitioning, *Chem. Geol*., 164, 21-34, 2000.

J. Apatite:

1) Prowatke and Klemme Trace element partitioning between apatite and silicate melts, *Geochim. Cosmochim. Acta*, 70, 4523-4527, 2006.

III. Effects of Liquid Composition and Temperature

A. Geothermometry

1) Watson, Wark and Thomas, Crystallization thermometers for zircon and rutile, *CMP*, 151, 413-433, 2006.

2) Witt-Eickeshen and O'Neill, The effect of temperature on the equilibrium distribution of trace elements between cpx, opx, ol, and spinel in upper mantle peridotites, *Chem. Geol*., 221, 65-108, 2005.

B. Role of H_2O:

1) Green, Blundy, Adam and Yaxley, SIMS determination of trace element partition coefficients between garnet, clinopyroxene and hydrous basaltic liquids at 2-7.5 Gpa and 1080˚-1200˚C, *Lithos*, 53, 165-167, 2000.

2) Wood and Blundy, The effect of H_2O on crystal melt partitioning of trace elements, *Geochim. Cosmochim. Acta*, 66, 3647-3656, 2002.

3) Gaetani, Kent, Grove, Hutcheson and Stolper, Mineral/melt partitioning of trace elements during hydrous peridotite partial melting, *Contrib. Mineral. Petrol.*, 145, 391-405, 2003.

C. Role of Melt Composition in Controlling Partition Coefficients:

1) Kohn and Schofield, The importance of melt composition is in controlling trace element behavior and an experimental study of Mn and Zr partitioning between forsterite and silicate melts, *Chem. Geol.*, 117, 73-87, 1994.

2) O'Neill and Eggins, The effect of melt composition on trace element partitioning: an experimental investigation of the activity coefficients of FeO, NiO, CoO, MoO_2 and MoO_3 in silicate melts, *Chem. Geol.* 186, 151481, 2002.

3) Gaetani, The influence of melt structure on trace element partitioning at the peridotite solidus, *Contrib. Mineral. Petrol.*, 147, 511-527, 2004.

4) Mysen, B.O., Element partitioning between minerals and melt, melt composition and melt structure, *Chem. Geol.*, 229, 162-172, 2004.

5) Miller, Asimov and Burnett, Determination of melt influence on divalent element partitioning between anorthite and CMAS melts, *Geochim. Cosmochim. Acta*, 70, 4258-4274, 2006.

6) Klein, M., Stosch, H.-G., Sack, H.A. and Shimizu, N., Experimental partitioning of high field strength and rare earth elements between clinopyroxene and garnet in andesite to tonalitic systems, GCA, 64, 99-115, 2000.

7) Blundy and Dalton, Experimental comparison of trace element partitioning between clinopyroxene and melt in carbonate and silicate systems and implications for mantle metasomatism, *Contrib. Mineral. Petrol*. 139, 356-371, 2000.

D. Mineral-Aqueous Fluid Partitioning

1) Stalder, Foley, Brey and Horn, Mineral-aqueous fluid partitioning of trace elements at 900˚-1200˚C and 3.0-5.7 Gpa: New experimental data for garnet, clinopyroxene, and rutile and implications for mantle metasomatism, *Geochim. Cosmochim. Acta*, 62, 1781-1801, 1998.
2) John, Scherer, Haase and Schenk, Trace element fractionation during fluid-induced eclogitization in a subducting slab: trace element and Lu-Hf-Sm-Nd isotope systematics, *EPSL*, 227, 441-456, 2004.
3) Kessel, Schmidt, Ulmer and Pettke, Trace element signature of subduction zone fluids, melts and supercritical liquids at 120-180 km data, *Nature*, 437, 724-727, 2005.

IV. Controls on Core Formation

1) Corgne, Keshav, Fei, and McDonough, How much potassium is in the earth's core? New insights from partitioning experiments, *EPSL*, 256, 567-576, 2007.
2) Corgne, Keshav, Wood, McDonough and Fei, Metal-silicate partitioning and constraints on core composition and oxygen fugacity during Earth accretion, *GCA* 72, 574-589, 2008.
3) Malavergne, Tarrida, Combes, Bureau, Jones and Schwandt, New higher pressure and high-temperature metal/silicate partitioning of U and Pb: Implications for the cores of Earth and Mars, *GCA*,71, 2637-2655, 2007.

4) Mills, Agee and Draper, Metal-silicate partitioning of cesium: Implications for core formation, *GCA*, 71, 4066-4081, 2007.

5) Cottrell and Walker, Constraints on core formation from Pt partitioning in mafic silicate liquids at high temperature, *GCA*, 70, 1565-1580, 2006.

6) Chabot, Campbell, James, Humayun and Lauser, The influence of carbon on trace element partitioning behavior, *GCA*, 70, 1322-1335, 2006.

V. Metamorphic Processes

1) Marshall, Altherr, Ludwig, Kalt, Gméling and Kasztovszky, Partitioning and budget of Li, Be, and B in high-pressure metamorphic rocks, *GCA*, 70, 4756-4764, 2006.

2) Xiao, Sun, Hoefs, Simon, Zhang, Li and Hofmann, Making continental crust through slab melting: Constraints from niobium-tantalum fractionation in UHP metamorphic rutile, *GCA*, 70, 4770-4782, 2006.

12.479 Trace-Element Geochemistry

Spring 2013