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SUBJECT INDEX

Papers are listed under subject headings based on symposia organised for the Goldschmidt Conference in Edinburgh in August-September, 1994. Sub-headings are used for the larger symposia, and often these sub-headings cover material which overlaps several symposia. The subject headings and their research areas are briefly outlined below, and these are followed by listings of the papers in alphabetical order under each subject heading or sub-heading.

1. **Theoretical geochemistry** - applications of theoretical mineral physics to mineral chemistry and element distribution, including aspects of diffusion; ab initio methods.
2. **Experimental geochemistry** - laboratory experimental studies across the full spectrum of P-T conditions.
3. **Geochemical techniques** - developments in instrumentation and techniques; special applications and programmes.
4. **Weathering and erosion, deposition and diagenesis** - geochemical processes in low temperature rock degradation and genesis.
5. **Groundwater chemistry and palaeohydrology** - geochemical characterisation of groundwater systems and of time dependent hydrogeological changes, significance to palaeoenvironments, prognoses of future changes.
6. **Waste containment and pollutant transport** - geochemical assessment of the contols and risks of all types of waste and pollutant disposal.
7. **Ocean composition and fluxes during the Quaternary** - high resolution documentation of changes in marine geochemistry, and geochemical indicators of recent events.
8. **Ocean palaeochemistry and the evolution of the ocean basins** - the gocchemistry of ocean evolution in the pre-Quaternary.
9. **Modern submarine hydrothermal processes** - contols on the geochemical reactions within sub-seafloor hydrothermal systems, and their spatial and temporal variability.
10. **Mechanisms of isotopic and chemical communication in crust and mantle rocks** - application of new microanalytical (ion and laser probe) techniques to constrain micron to millimetre scale processes in rocks, and their relevance to macroscopic studies of mass and heat transport.
11. **Partitioning of elements** - new data on partition coefficients for mineral, melt, fluid phases as determined by experiment or measurement of natural phases; including aspects of the distribution of precious metals.
12. **Dehydration, partial melting and fluid distribution in the crust** - covering both the geochemistry of high-temperature processes in the continental crust and the modification of crust undergoing subduction.
13. **Magma generation processes** - geochemical evidence of the generation and evolution of mantle-derived melts.
14. **Mantle development in space and time** - geochemical and mineralogical information on mantle constitution.
15. **Geochronometry and thermal history** - quantitative thermal histories of rocks and metamorphic belts.

1. Theoretical geochemistry

D'Arco, P, Sandrone, G, Dovesi, R, Saunders, V R — Ab initio study of the relative stability under pressure of $MgSiO_3$-ilmenite, -perovskite, and (periclase + stishovite)

Edwards, A, Freer, R, Catlow, C R A — Combined experimental and computer simulation studies of cation diffusion in silicate garnets

Made, B J A D — Empirical relations to estimate kinetic constants of silicates

Matsui, M — A transferable interatomic potential model for crystals and melts in the system $CaO–MgO–Al_2O_3–SiO_2$

Parker, S C — Atomistic simulation studies of mineral surfaces and the role of impurities on their structure and stability

Silvi, B, Savin, A — Chemical bonds in minerals: Topological analysis of the electron localization function

Tossell, J A — Theoretical studies of the speciation of Sb in sulphidic solutions

Vocadlo, L, Wall, A, Parker, S C, Price, G D — Absolute ionic diffusion in MgO: computer calculations via lattice dynamics

Wentzcovitch, R M, Ross, N L, Price, G D — Ab initio constant pressure molecular dynamics study of silicate perovskites

Wright, K, Freer, R, Catlow, C R A — Oxygen diffusion and water-related defects in feldspar minerals: information from experimental and modelling studies

Xiao, Y, Lasaga, A C — Applications of ab initio quantum mechanical potential surfaces to mineral physics calculations

Zheng, Y-F — Oxygen isotope fractionation in metal monoxides

2. Experimental geochemistry

2a. Experimental constraints on melting in the mantle

See listing under section 13*a*

2b. Acidic and other melts and fluids at high P and T

Baker, D R, Vaillancourt, J — The viscosity of $F + H_2O$-bearing peralkaline and peraluminous rhyolitic melts

Ballhaus, C — C-H-O fluid speciations under mantle conditions

Blencoe, J G — Calculated activities for species in albite-water melts

Davies, A, Wood, B J, Barry, T, Dinsdale, A, Gisby, J — The thermodynamics of mineral-melt equilibria in the system $CaO–MgO–Al_2O_3–SiO_2$

Frost, D J, Wood, B J — Carbon dioxide fugacities at high temperature and pressure

Gessmann, C, Spiering, B, Raith, M — Experimental investigation of the Fe-Mg-partitioning between garnet and biotite with respect to the influence of Ti in biotite

Henderson, G S, Fleet, M E — The structure of Ti-silicate glasses by Raman spectros-copy: Implications for the role of Ti in natural melts

Hudon, P, Baker, D R, Pelton, A D, Wu, P — Disappearance of the liquid-liquid miscibility gap in the system $CaO–MgO–SiO_2$ at high pressure

Hurwitz, S, Lyakhovsky, V, Navon, O — Diffusive growth of water bubbles in rhyolitic melts

Kadik, A A, Shilobreeva, S, Vernadsky, V — The primary carbon and the formationof carbon species in terrestrial magmas

Kohn, S C, Brooker, R A — The effect of water on the solubility and speciation of CO_2 in aluminosilicate glasses along the join SiO_2-$NaAlO_2$

Konzett, J, Ulmer, P, Sweeney, R J, Thompson, A B — Phase relations and chemistry of richteritic amphiboles in the system $K_2O–Na_2O–CaO–MgO–Al_2O_3–SiO_2–H_2O$ (KNCMASH)

Luth, R W — Carbonation reactions in eclogites at high pressure: implications for carbonic fluids in the mantle

Manning, C E — Experimental determination of the solubilities of quartz, kyanite and corundum in H_2O in the lower crust and mantle

Marr, R A, Baker, D R, Williams-Jones, A E — Alkali zirconosilicate speciation in halogen-rich, felsic, peralkaline magmas
Mungall, J E, Dingwell, D B — Effects of water content, temperature and pressure on actinide tracer diffusion in melts of haplogranitic composition
Popp, R K, Virgo, D, Yoder, H S, Hoering, T C, Phillips, M W — The role of hydrogen fugacity in controlling Ferric-Ferrous ratio and volatile content of Kaersutitic amphibole : an experimental study
Shen, A H, Chou, I, Bassett, W A — Experimental determination of PVTX relations of fluids in the diamond-anvil cell
Snyder, D, Gier, E, Carmichael, I — Experimental measurements of the thermal conductivity of molten silicates
Thompson, P — The sanidine - 'sanidine hydrate' reaction boundary
Wood, B J, Brodholt, J P — The density of water to 25kbar/1873K

2c. Mantle mineralogy and the transition zone

Gasparik, T — Experimentally determined melting relations in simple and complex chemical systems at pressures up to 23 GPa
Harte, B, Harris, J W — A review of natural mineral assemblages from the mantle transition zone
Harte, B, Hutchison, M T, Harris, J W — Trace element characteristics of the lower mantle - An ion probe study of inclusions in diamonds from Sao Luie
Irifune, T — Phase transformations in pyrolite and subducted crust compositions down to a depth of 800 km in the lower mantle.
Kesson, S E, FitzGerald, J, Shelley, J M — Phase relations for the former basaltic crust of the slab in the perovskitite facies of the lower mantle
Pawley, A R, Wood, B J — Talc dehydration to 50 kbar: constraints on the volume of H_2O at high pressure
Ulmer, P, Trommsdorff, V, Reusser, E — Experimental investigation of antigorite stability to 80 kbar
Wood, B J, Helffrich, G — Mantle stratification: constraints from mineral physics, seismological and phase equilibrium data

2d. Mineral dissolution, interfaces and hydrothermal solutions

Azaroual, M, Pauwels, H, Mcunier, A, Sardini, P — Fluid flow equipment for hydrothermal investigations: apparatus and preliminary results
Bateman, K, Noy, D J, Pearce, J M, Savage, D — Coupled flow and reaction: a modelling and experimental study of zeolite diagenesis
Bebie, J, Hovey, J, Seward, T M — Thallium (1) chloride complexing in aqueous media to 200°C
Benezeth, P, Diakonov, I, Pokrovski, G, Dandurand, J J, Schott, J — Gallium solubility and aqueous speciation in hydrothermal solutions (60–125°C). Experimental study and comparison with aluminium
Benning, L G, Seward, T M — Hydrosulphide complexes of gold (I) at high pressures and temperatures: equilibrium and kinetic problems
Casey, W H, Rock, P A, McBeath, M M, Walling, E M, Chung, J-B — A new method for determining excess Gibbs energies in binary metal-carbonate solid solutions
Devidal, J-L, Dandurand, J-L, Gout, R — Solubility of kaolinite in alkaline solutions at hydrothermal conditions
Diakonov, I, Pokrovski, G, Castet, S, Schott, J, Gout, R — Experimental study of Na-Al complexing in hydrothermal solutions
Finley, J B, Nordstrom, D K — Evaluation of the chemical model in WATEQ4F: 1. The major ion activity coefficients - Na, K, Ca, Mg, Cl
Fouillac, C, Azaroual, M — Comparison between actual and theoretical dissolution rates in a granite-water interaction experiment at 180°C and 14 bar
Gammons, C H, Williams-Jones, A E, Yu, Y — New data on the stability of gold(I) chloride complexes at 300°C

Gammons, C H, Wood, S A, Williams-Jones, A E	Experimental investigation of the stability of neodymium chloride complexes at 300°C
Gehring, A U, Schosseler, P M, Luster, J	The chemical form of Mn(II) and V(IV) in mineral phases as determined by EPR spectroscopy
Hellmann, R	A leached layer hydrolysis model: A better way to understanding feldspar dissolution at elevated temperatures and pressures
Merino, E, Wang, Yutian, Wang, Yifeng, Nahon, D	Implications of pseudomorphic replacement for reaction-transport modelling in rocks
Mountain, B W, Seward, T M	The solubility of sparingly-soluble minerals at 25°C using a flow-through column
Oelkers, E H, Schott, J	Experimental study of kyanite dissolution rates as a function of Al and Si concentration
Pokrovski, G, Schott, J, Sergeyev, A	Determination of the sodium-borate association constant $NaB(OH)_4^0$ between 75 and 200°C using new sodium selective glass electrodes
Pokrovskii, V A, Helgeson, H C	Calculation of the effect of $KAl(OH)O_4$ formation on the solubility of corundum at high pressures and temperatures
Rochelle, C A, Bateman, K, MacGregor, R, Pearce, J M, Savage, D, Wetton, P	Migration of cement pore fluids from a radioactive waste respository: Experimental studies of chlorite dissolution rates
Seward, T M, Henderson, C M B, Charnock, J M, Dobson, B R	A synchrotron EXAFS study of hydrothermal $AgNO_3$ solutions
Small, J S, Manning, D A C	Competition between metal-carboxylate complexing, mineral precipitation, and carboxylate decomposition reactions
Small, J S, Manning, D A C	On-line monitoring of clay mineral precipitation in sandstone porespace under flow conditions
Valsami-Jones, E, Bailey, E H, Ragnarsdottir, K V	Experimental investigation of the solubility of uranium (VI) under hydrothermal conditions
Wogelius, R A, Refson, K, Fraser, D G, Goff, J P, Grime, G W	Hydration reactions at the mineral-fluid interface: Experimental and computational studies

2e. Stable isotope partitioning.

Bezmen, N I	The above liquidus inhomogenity and cluster differentiation of fluid magmatic melts
Cole, D R	Oxygen isotope exchange rates in mineral-fluid systems: correlations and predictions
Driesner, T, Seward, T M	Effects of dissolved salts on calcite-water oxygen stable isotope fractionation at elevated temperatures and pressures
Rosenbaum, J M, Mattey, D P, Elphick, S	Equilibrium garnet-calcite oxygen istope fractionation
Tennie, A, Hoffbauer, R, Hoernes, S	Experimental determination of the oxygen isotope fractionations in the systems kyanite-calcite and talc-carbonate-water
Zheng, Y-F, Metz, P, Satir, M	Experimental calibration of oxygen isotope fractionation between calcite and tremolite in the presence of CO_2-H_2O fluid and a new data processing method for three phase systems

3. Geochemical techniques, instrumentation and special applications.

Galer, S J G, Laue, H-J, Goldstein, S L, Mezger, K, Hofmann, A W	Concept of a new thermal isotope mass spectrometer
Hallbauer, D K	Geochemical trace element analysis for ionic species by capillary electrophoresis

Halliday, A N, Lee, D-C, Christensen, J N, Yi, W, Hall, C M, Jones, C E, Teagle, D, Walder, A J, Freedman, P A — I.C.P. magnetic sector multicollector mass spectrometry and its applications to geochemistry

Holdham, M T, Jarvis, I — A new method for the determination of the platinum group elements in sedimentary materials

Lahtinen, R, Lestinen, P, Korkiakoski, E, Salminen, R, Sandstrom, H, Savolainen, H, Vallius, H — Rock geochemistry research project (RGRP) in the Geological Survey of Finland

Petit, J-C — Applying MeV ion beam techniques to geochemical issues: Cross-fertilizing nuclear physics and geosciences

Sackett, W — The utility of sediment pyrolysis

van Moort, J C — The chemical composition and paramagnetism of auriferous quartz

4. Weathering and erosion, deposition and diagenesis

4a. Early diagenesis

Albrecht, A, Beer, J — The use of ^{137}Cs and ^{210}Pb to model erosive processes in high altitude settings; The Muttsee (Switzerland) example

Bailey, A M, Roberts, H H, Blackson, J H — Diagenetic mineral formation in sediments of the Mississippi River delta plain

Burdige, D J, Dhakar, S P — Mathematical models of diagenetic processes in marine sediments: iron and manganese redox cycling and non-steady state diagenesis

Coleman, M — Why diagenetic carbonate concretions form: localised microbial buffering

Cundy, A B, Croudace, I W — Geochemical studies of salt marsh sediments: Evidence for possible ^{210}Pb mobility

Davison, W, Zhang, H, Miller, S — Developing and applying new techniques for measuring steep chemical gradients of trace metals and inorganic ions at the sediment-water interface

Donahoe, R J, Liu, C, Dobson, K, Graham — Cycling of iron and manganese in a Riparian wetland

Furukawa, Y, Barnes, H L — Replacement mechanisms among iron sulphide minerals

Gonzalez-Lopez, J M, Fernandez-Nieto, C, Lopez-Galindo, A, Torres-Ruiz, J — Carbonates associated with the Almazan sepiolite-palygorskite deposits (northern Spain)

Holdham, M T, Jarvis — A new method for the determination of the platinum group elements in sedimentary materials

Ingri, J, Torssander, P, Andersson, P S, Morth, C-M — Hydrogeochemistry of sulphur isotopes in the Kalix River catchment, northern Sweden

Krom, M, Davison, P, Zhang, H, Davison, W — High resolution sampling of pore waters using a gel probe from Eshwaite Water, Lake District

Krupp, R E, Suleimenov, O M — Thermodynamics of aqueous H_2S solutions at elevated temperatures: solubility and first dissociation constant

Luck, J-M, Ben Othman, D — Trace Pb, Zn, Cd, Tl contents and Pb-Sr radiogenic isotopes in the dissolved and particulate phases of a river during high-water stage: constraints on the origin(s) and transport of the metals

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Sackett, W	The utility of sediment pyrolysis
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4b. Weathering of geological systems

Bricker, O P	Weathering and mass-balance budgets in small catchments
Cochran, M F, Berner, R A	Vegetative enhancement of chemical weathering
Faure, G, Nishiizume, K	Exposure dating of quartz sandstone in the Transantarctic Mountains by cosmogenic ^{10}Be and ^{26}Al
Gislason, S R, Arnorsson, S, Armannsson, H	Present chemical weathering of basalt in Iceland
Holland, H D, Kuo, P H, Rye, R O	O_2 and CO_2 in the Late Archaean and Early Proterozoic atmosphere
Phillips, F M, Bowen, D Q, Elmore, D	Surface exposure dating of glacial features in Great Britain
Schwartzman, D	Biotic enhancement of weathering redux
Tranter, M, Brown, G, Sharp, M,	Chemical weathering beneath Alpine glaciers: rates and implications for CO_2 drawdown
White, A F, Blum, A E	Effects of climate on chemical weathering in watersheds underlain by granitoid rocks

4c. Weathering of minerals

Akagi, T, Nakai, S, Masuda, A	The tetrad effect, a general effect in partitioning of REE between aqua and solid
Brantley, S L, Stillings, L	An integrated model for feldspar dissolution under acid conditions
Cama, J, Ganor, J, Lasaga, A C	The kinetics of smectite dissolution
Dobrovolsky, E V	Replacement reactions during weathering: macrokinetic approach
Drever, J I, Murphy, K M, Clow, D W	Field weathering rates versus laboratory dissolution rates: An update
Ganor, J, Lasaga, A C	The effects of oxalic acid on kaolinite dissolution rate
Levy, D B, Amrhein, C	The coprecipitation of Mg and Si with calcium carbonate
Made, B J A D, Ben Baccar, M, Fritz, B	Geochemical modeling of diagenetic reactions
Maurice-Johnsson, P A	Use of AFM in experimental surface geochemistry
May, F	Weathering or hydrothermal alteration? - Examples from the Rhenish Massif, Germany
Mogollon, J L, Perez, D, Lo Monaco, S, Ganor, J, Lasaga, A C	The effect of pH, $HClO_4$, HNO_3 and delta Gr on the dissolution rate of natural gibbsite using column experiments
Mountain, B W, Williams-Jones, A E	Experimental simulations of fluid-rock interaction: The effect of surface area on the rate of alteration
Ngwenya, B T, Shimmield, G B, Elphick, S C	An experimental study of fluid-rock interaction: application to groundwater aquifers
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4d. Diagenesis of rocks

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Bustillo, M, Bustillo, M A — REE study in Jurassic radiolarites fromthe subbetic, Betic Cordillera, Spain
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4e. Experimental studies of mineral dissolution, interfaces and hydrothermal solutions

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5. Groundwater chemistry and palaeohydrology

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Caritat de, P — Time-dependent variations in groundwater chemistry: the Norwegian groundwater monitoring network

Cave, M, Reeder, S, Metcalfe, R — Chemical characterisation of core pore-waters for deep borehole investigations at Sellafield, Cumbria

Dearlove, J P L — Baseline hydrogeochemical study of shallow groundwaters in N E England

Fritz, S J, Harvey, F E, Drimmie, R J, Johnston, C, Frape, S K — Tritium variability of repeated samplings of well waters in south Ontario

Gascoyne, M — Isotopic and geochemical evidence for old groundwaters in a granite on the Canadian shield

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Szikszay, M, Alexandre, G A L, Toledo, M C M, Hypolito, R, Shimizu, D	Study of mobility of Zn, Co, Cu and Pb the unsaturated zone in tropical climate
Taubald, H, Satir, M	Carbonates in mineral clay liners: a risk for long-term security of waste disposal sites? Experimental, geochemical, and isotopic constraints
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Muzuka, A N N	Episodes of ice rafted debris and their effects on primary productivity in the Labrador Sea for the past 31,000 years
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Andersson, E, Holm, N G	An experimental approach for studying the stability of organic compounds under simulated submarine hydrothermal conditions.
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Berndt, M E, Seal, R R, Shanks, W C, Seyfried, W E	D/H fractionation during phase separation of seawater in subseafloor hydrothermal systems : Isobaric heating and adiabatic decompression.
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10. Mechanisms of isotopic and chemical communication in crust and mantle rocks

10a. Small-scale evidence of geochemical processes in mantle rocks and ultrabasic complexes

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10b. Spatial distribution of isotope and trace element variations in rocks and magmas, and their implications

Abart, R	Isotopic disequilibrium during metasomatic vein formation
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11. Partitioning of elements

11a. Partition coefficients for silicate melts, minerals and associated fluids

Barclay, J, Carrol, M R	Volatile and trace element partitioning for a peralkaline rhyolite volcano
Beattie, P	What determines the values of mineral/melt partition coefficients?
Blundy, J D, Wood, B J	Energetics of element partitioning between minerals and melts
Brenan, J M, Shaw, H F, Phinney, D L	Experimental determination of trace element partitioning between pargasitic amphibole and hydrous silicate melt
Dalpe, C, Baker, D R	Partition coefficients for rare-earth elements between calcic amphibole and Ti-rich basanitic glass at 1.5 Gpa, 1100°C
Foley, S F, Jenner, G A, Jackson, S E, Fryer, B J	Trace element partition coefficients between phlogopite, clinopyroxene and matrix in an alkaline lamprophyre from Newfoundland, Canada
Harte, B, Kirkley, M B	Variations in REE, Y and Zr partitioning between clinopyroxene and garnet as a function of major element composition
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Johnson, K T M	Experimental cpx/ and garnet/melt partitioning of REE and other trace elements at high pressures
Klein, M, Seck, H A, Stosch, H G, Shimizu, N	Experimental REE partitioning between amphibole, clinopyroxene, garnet and basaltic to tonalitic melts:
Kravchuk, I F	Experimental study of elements partitioning in equilibria melt-fluid at high pressure
Libourel, G, Deloule, E, Toplis, M J	Phosphorus partitioning in basalts: an experimental and ion probe study
Nielsen, R L, Forsythe, L M, Hack, P J, Gallahan W E, Fisk, M R, Johnston, A D	The compositional dependence of HFSE partitioning: a comparison between Pyroxene- and Magnetite-melt systematics.
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Ryabchikov, I D	Experimental data on major and trace element partitioning in partially molten carbonated peridotites
Sweeney, R, Prozesky, V, Przybylowicz, W	Trace element partitioning between silicate minerals and carbonatite and silicate melts at 18kb to 46kb pressure
Urusov, V S	Theoretical estimations of equilibrium partitioning of elements between crystals and binary melts (fluids)

11b. Partitioning of sulphide phases and precious metals

Barnes, S-J, Makovicky, E, Karup-Moller, S, Makovicky, M, Rose-Hansen, J	Partition coefficients for Ni, Cu, Pd, Pt, Rh and Ir between monosulphide solid solution and sulphide liquid and the implications for the formation of compositionally zoned Ni-Cu sulphide bodies by fractional crystallization of sulphide liquid
Capobianco, C J, Drake, M J	Partitioning and solubility of PGEs in oxides and silicates
Dobrovolskaya, M G, Basalaeva, I V, Vikentyev, I V	Precious metals (Pt, Pd, Au, Ag) in copper-pyritic deposits of the South Urals
Fleet, M E, Crocket, J H, Stone, W E	Sulphide liquid/silicate melt partition coefficients for platinum-group elements and gold
Fleet, M E, Wu, T-W	Experiments on the volatile transport of precious metals at 1000°C
Shcherbakov, Y G	Geochemical properties of natural systems

Shengrong, L, Zhenmin, G	Some typical partition and distribution patterns of platinum group elements
Sobolev, R N	Gold behavior in the process of the acid magma crystallization
van Moort, J C	The chemical composition and paramagnetism of auriferous quartz

12. Dehydration, partial melting and fluid distribution in the crust

Barnicoat, A C, Cartwright, I,	Focused fluid flow during subduction
Benner, E, Hoernes, S,	Stable isotope systematics in metasediments of the Scottish Highlands
Bickle, M J, Chapman, H J, Fallick, A, Ferry, J M, Rumble, D	Oxygen, carbon and strontium isotopic constraints on fluid movement during the Acadian metamorphism in south-central Maine
Brandon, A D, Creaser, R A, Chacko, T	Rapid ascent of granitoid magmas from the lower crust
Braun, I, Raith, M	The leptynitic gneisses of the Kerala Khondalite Belt, southern India: phenomena and mechanism of dehydration/melting at granulite facies conditions
Brown, M	Melt segregation mechanism controls on the geochemistry of crustal melts
Buick, I S, Cartwright	Fluid–rock interaction across a greenschist-to granulite-facies transition, Reynolds Range, central Australia
Cameron, E M, Hattori, K	Highly oxidized deep metamorphic zones: occurrence and origin
Carrington, D P, Watt, G R	Contrasting geochemistry of granulite-facies leucosomes and S-type granites: K-feldspar as culprit
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Chacko, T, Creaser, R A, Poon, D	Spinel + quartz granites and associated metasedimentary enclaves from the Taltson Magmatic Zone, Alberta, Canada
Cole, C, Graham, C,	Stable isotope and textural evidence on the mechanisms of metamorphic fluid infiltration within a zone of structurally focused high fluid flux
Delgado, J, Venemann, T, O'Neil, J R	The origin of metasomatic fluids in skarns from La Maladeta (Central Pyrenees, Spain): C, O, H, S and Sr isotope compositions
Dunai, T J	Mantle-derived CO_2 and granulite genesis: evidence from noble gases
Fitzsimons, I C W	Cordierite migmatites from East Antarctica - geochemical constraints on volatile distribution during crustal anatexis
Forster, H-J, Tischendorf, G	Evolution of the Hercynian granite magmatism in the Erzgebirge metallogenic province
Harley, S L	Cordierite as a sensor of fluid and melt distribution in crustal metamorphism
Harris, N, Ayres, M, Massey, J	Chemical disequilibrium during crustal anatexis
Heming, G	The tectonogeochemical dynamic system in dexing porphyry copper deposit, Southeast of China
Hensen, B J, Osanai, Y	Experimental study of dehydration melting of F-bearing biotite in model pelitic compositions
Holness, M, Fallick, A E	Palaeohydrology of the Beinn an Dubhaich aureole, Skye, and inferred mechanisms of fluid infiltration in carbonates
Huizenga, J M, Touret, J L R	Fluid inclusion compositions as a geo-thermobarometer: Example of the Umwindsi shear zone, NE Zimbabwe
Kotkova, J	Are North Bohemian felsic granulites products of HT-HP melting?

Lewis, A J, Palmer, M R, Kemp, A J	Variations of the rare earth element abundances in hydrothermal waters from the Yellowstone hydrothermal system, Wyoming, USA
Massey, J	Contrasting fluid-deformation-melt histories within the high Himalayan crystallines, Langtang Valley, Nepal
Metcalfe, R, Bevins, R E, Robinson, D	Theoretical constraints on calcium silicate domain formation and fluid flow during alteration of basic igneous rocks
Moller, A, Mezger, K, Schenk, V	Reconstruction of crustal genesis in a high-grade gneiss terrane using Sm/Nd-whole rock systematics and Pb-isotopes of leached feldspar
Mozgova, N N, Borodaev, Y S, Gandhi, S M	Partial melting features of metamorphosed ores from Rangpo polymetallic deposit (Sikkim, India)
Nabelek, P I	Dehyrdration melting and differential uplift of a partially molten crust in the Black Hills, South Dakota, USA
Patino-Douce, A E	Melt generation in the continental crust: answered and unanswered questions
Pattison, D R M, Begin, N J	Hierarchy of closure temperatures in granulites and the importance of an intergranular exchange medium (melt?) in controlling maximum Fe-Mg exchange
Philippot, P	Fluid and halogen activities in the high-grade blueshists from the Dora-Maira Massif, Western Alps
Poitrasson, F, Montel, J-M, Duthou, J-L, Pin, C, Chenery, S	Hydrothermal remobilisation of Sm-Nd isotopes at the mineral scale in granites
Putlitz, B, Schliestedt, M, Matthews, A	Fluid and geochemical constraints on the formation and retrogression of high-pressure metamorphic rocks from Sifnos (Greece)
Skelton, A D L	Fluid flow in Vermont & New Hampshire, USA: A 3-D perspective
Spear, F	P-T-t evolution of the Valhalla complex, British Columbia, Canada
Touret, J L R	Fluid-absent and fluid-dominated domains in granulites and eclogites
Treloar, P J, Wheeler, J, Potts, G J	Metamorphism and melting within the Nanga Parbat syntaxis, Pakistan Himalaya
Vielzeuf, D, Montel, J M	Experimental constraints on partial melting in the crust
Waters, D J	Textural studies of migmatitic granulites: solid-melt reactions and the role of fluids
Wickham, S M	Batholithic K-rich silicic magmatism in east-central Asia: evidence for a mantle source for progressive regional crustal potassium enrichment.
Wilson, M R, Dunning, G R, Cawood, P A	Fluid compositions in crustal-scale plumbing systems related to contrasting styles of Ordovician and Silurian orogenesis, Northern Appalachians, Newfoundland
Yardley, B W D, Banks, D A	The ligand chemistry of crustal fluids
Yaxley, G M, Green, D H, Klapova, H	The refractory nature of carbonate during partial melting of eclogite: evidence from high pressure experiments and natural carbonate-bearing eclogites

13. Magma generation processes

13a. Experimental constraints on melting in the mantle

Baker, M B, Stolper, E M	The composition of high-pressure mantle melts: results from diamond aggregate experiments

Danyushevsky, L V, Green, D H, Falloon, T J, Sobolev, A V — The compositions of anhydrous and H_2O-undersaturated melts in equilibrium with refractory peridotites at 15 and 20 kb: Implications for high-Ca boninite petrogenesis

Gaetani, G A, Grove, T L — Melting in the sub-arc mantle: the effects of H_2O on primary magmas and the spinel-to-garnet transition

Green, D H — Experimental definition of mantle melting and implications for mantle dynamics

Kinzler, R J — Melting of mantle peridotite at pressures approaching the spinel to garnet transition

Kushiro, I — Melting behaviour of mantle peridotites and compositional variations of partial melts at high pressures

Rapp, R P — Partial melting of metabasalts at 2–7 GPa

Robinson, J A C, Wood, B J — Low degree hydrous and anhydrous partial melting of peridotite

Soulard, H, Wood, B J — Lherzolite partial melting: closer to primary liquids

13b. Source regions, extraction and evolution of basaltic melts

Albarede, F, Bachelery, P, Fitton, J G, Joron, J L, Kaminski, E, Luais, B, Semet, M, Upton, B — Time scales and mechaisms of geochemical fluctuations in the Piton de la Fournaise volcano, Réunion Island

Andronikov, A V — Glass in lherzolite inclusions from Jetty Peninsula (East Antarctica)

Aparicio, A, Arana, V, Garcia, R, Grachev, A — The origin of the Columbretes Islands, Basanitic and phonolitic magmas (Western Mediterranean)

Baker, J, Menzies, M, Snee, L, Thirlwall, M — Stratigraphy, $^{40}Ar/^{39}Ar$ geochronology and geochemistry of flood volcanism in Yemen

Barling, J — Origin and evolution of a high-Ti ocean island basalt suite: The Laurens Peninsula Series, Heard Island, Indian Ocean

Bell, K — Carbonatites and mantle evolution: A review

Brake, C R, Fitton, J G — Tholeiitic magmatism in the Belingwe greenstone belt

Churikova, T G — Modelling of the magmatic process of the PlosKie Sopky volcano

Class, C, Goldstein, S L — Ocean island basalts and lithospheric melting: constraints from the source mineralogy

Cohen, A S, O'Nions, R K — Variations in the Th/U ratio and Th isotope compositon of Mauna Loa tholeiites

Crawford, A J, Kamenetsky, V S, Lanyon, R, Varne, R — Macquarie Island: interactions between the Balleny HIMU plume and the southeast Indian ridge: metasomatism of MORB source mantle and contamination of MORB magmas

Ellam, R M, Olive, V, Mitchell, C — Compositional variations in the sub-continental lithospheric mantle and implications for its role in basalt petrogenesis

Elthon, D — Refertilization in a convecting mantle: effects on primary MORB compositions

Fitton, J G, Saunders, A D, Harðarson, B S, Shipboard Scientific Party — Constraints on the nature of the Iceland plume from ODP Leg 152 (south-east Greenland volcanic rifted margin)

Furman, T, Graham, D — Chemical and isotopic variations in volcanic rocks from the Rungwe Province

Garland, F, Turner, S, Hawkesworth, C, Kerstein, L — Major element modelling of changes in lithospheric source with time for the Parana CFB

Goldstein, S J, Perfit, M R, Batiza, R, Fornari, D J, Murrell, M T — ^{226}Ra and ^{231}Pb systematics of axial MORB, crustal residence ages, and magma chamber characteristics at 9–10°N East Pacific Rise

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Grove, T L, Kinzler, R J, Gaetani, G A	Using constraints from experimental petrology to model mantle melting processes under anhydrous and hydrous conditions
Gurenko, A A, Chaussidon, M	Coexistence of enriched and depleted primitive melts as inclusions in olivine from Reykjanes tholeiites, Iceland
Haase, K, Goldstein, S L, Devey, C W, Stoffers, P	Magma genesis and mantle sources in the Easter hotspot–Easter Microplate system
Hanan, B B, Graham, D W, Michael, P J	Highly correlated lead, strontium, and helium isotopes in Mid-Atlantic Ridge basalts from a dynamically evolving spreading centre at 31–34°S
Harðarson, B S, Fitton, J G	Geochemical variation in the Tertiary basalts of Iceland
Hart, S R	Mantle plumes and other mail from the mantle
Hauri, E H, Wagner, T P, Kurz, M D	Melt generation and migration beneath Kilauea: Constraints from Os isotopes and phase equilibria
Hawkesworth, C J, Gallagher, K, Turner, S	Causes of melt generation in the sub-continental mantle
Hergt, J M, Storey, M, Marriner, G, Tarney, J	The Curaçao lava formation: Samples of the oldest and most primitive magmas from the Galapagos Plume
Hirschmann, M, Stolper, E M, Ghiorso, M S	Perspectives on shallow mantle melting from thermodynamic calculations
Huang, Y-M, van Calsteren, P, Hawkesworth, C, Black, P, Smith, I	OIB-like magmatism in Auckland, New Zealand
Iwamori, H, McKenzie, D	Melt segregation and P-T path of mantle melting
Kelemen, P B, Shimizu, N, Salters, V J M	Focussed flow of melt in the upper mantle: Extraction of MORB beneath oceanic spreading ridges
Kent, R, McKenzie, D	Rare earth element inversion models for basalts associted with the Kergelen mantle plume.
King, P M, Hawkesworth, C J, Rogers, N W	Magmatism and extension in the Azores
Langmuir, C H	Major element heterogeneity in the mantle: Constraints from a general model for basalt petrogenesis
McKenzie, D	Melt movement in the mantle
Meen, J K, Elthon, D	Ferrodiorites from the Mid-Cayman Rise
Michael, P J	Evidence from trace elements and H_2O from regionally distinctive sources of MORB : Implications for evolution of the depleted mantle
Mitchell, C, Fitton, J G, Al'mukhamedov, A L, Medvedev, A I	The age and duration of flood basalt magmatism : geochemical and palaeomagnetic constaints from the Siberian province
Molzahn, M, Reisberg, L, Worner, G	Isotopic studies (Sr, Nd, Pb, Os, O) of the Jurassic Ferrar flood-basalt province of Northern Victoria Land, Antarctica
Nielsen, R L, Crum, J, Bourgeois, R, Hascall, K, Forsythe, L, Christie, D M, Fisk, M R	Local diversity of MORB parent magmas: Evidence from melt inclusions in high-An feldspar from the Gorda Ridge
O'Hara, M J	Combining reversed and subdued discrimination with high relative concentrations of incompatible elements
O'Hara, M J	Superimposing magma chamber and melting regime processes: How easy is it to (mis)interpret the liquid products?
O'Hara, M J	Imperfect crystal-liquid separation processes
O'Hara, M J	Integrated melts from melting regimes of different shapes
Oskarsson, N, Grunvold, K, Sigvaldason, G E	Composition of basalts above the Iceland mantle plume
Peccerillo, A, Gazaegn. Y, Dereje, A	Genesis of acid volcanism in continental rift environments : a case in the Ethiopian Rift Valley
Rehkamper, M, Hofmann, A W	Trace element anomalies and correlations in Indian Ocean MORB

Reid, M R, Ramos, F C	Timescales of magma chamber processes from Th isotope systematics
Richardson, C, McKenzie, D	Radioactive disequilibria from two-dimensional models of melt generation in plumes and ridges
Rogers, N W, Hawkesworth, C J	Compositional variations in basalts from the Western Great Basin, California and Nevada, USA
Salters, V J M, Bourdon, B, Elliot, T E	Constraints on the MORB melting regime based on the Lu-Hf and Sm-Nd systematics
Shimizu, N	Depths of melting and melt extraction beneath mid-ocean ridges as recorded in melt inclusions
Shirey, S B, Barnes, S-J	Re-Os and Sm-Nd isotopic constraints on basaltic komatiitic volcanism and magmatic sulphide formation in the Cape Smith Foldbelt, Quebec
Sigmund, J, Keller, J	Amphibole and garnet bearing mantle xenoliths in the Kaiserstuhl, Germany: relation to diatreme and carbonatite
Sims, K W W	Correlated U-Th and Sm-Nd fractionation in Mid-Ocean Ridge and Ocean Island Basalts: Implications for basalt petrogenesis
Slater, L, Gronvold, K, Shimizu, N, McKenzie, D	Melting beneath the Theistareykir region, NE Iceland
Smith, A D	Mississippian Ocean Island Basalts from the western palaeo-pacific ocean in the Cache Creek terrane of British Columbia.
Sobolev, A V, Gurenko, A A, Shimizu, N	Ultra-depleted melts from Iceland: data from melt inclusion studies
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Stewart, K, Kelley, S, Turner, S, Hawkesworth, C, Mantovani, M	3-D ^{40}Ar-^{39}Ar geochronology in the Parana flood basalt province
Wall, F, Barreiro, B A, Spiro, B	Isotopic evidence for late-stage processes in carbonatites: rare earth mineralization in carbonatites and quartz rocks at Kangankunde, Malawi
Widom, E, Hoernle, K, Shirey, S B, Schmincke, H-U	Os isotope systematics in the Canary Islands
Wilson, M, Rosenbaum, J M, Downes, H	Evolution of the European mantle lithosphere, a Sr-Nd-Pb isotope perspective
Woodhead, J D	The geochemistry of Mangaia (Cook Islands) and evaluation of the recycling model for the origin of the HIMU OIB signature

13c. Melt generation at destructive margins

Falloon, T J, Green, D H, Jacques, A L	Refractory magmas in back-arc basin settings - experimental constraints on a Lau Basin example
Forde, E J, Thirlwall, M F, Vroon, P Z, Hall, R	Geochemical constraints on source contributions to the Neogene intraoceanic arc volcanism in Halmahera, Eastern Indonesia
Kamenetsky, V S, Sobolev, A V	Geochemical constraints on genesis of Kamchatka Arc ultramafic melts
Kelemen, P B	Origin of High Mg# andesite and the continental crust
Kersting, A, Arculus, R	Pb systematics of Klyuchevskoy volcano, Kamchatka and North Pacific sediments:
Kilian, R, Stern, C E	New trace elements and isotopic constraints on the genesis of andesites and dacites of the Quaternary Austral volcanic zone of the Andes
Korkmaz, S, Tuysuz, N, Kurt, H, Arslan, M	Geochemistry and evolution of the volcanism in the eastern Pontides, NE-Turkey

Murphy, M D, Brewer, T S	Geochemistry of mafic magmas from Sollipulli Volcano, southern Chile : constraints on models of magma genesis in the Southern Volcanic Zone of the Andes
Pearce, J A, Parkinson, I J, Peate, D W	Geochemical evidence for magma generation above subduction zones
Turner, S, Hawkesworth, C, Macdonald, R, Black, S, van Calsteren, P	Th, Ph, Nd and Sr isotope variations in volcanic rocks from the Lesser Antilles
Verma, S P	Geochemical and isotopic constraints on the origin of the mafic volcanism in central Mexico
Vroon, P Z, Lowry, D, Van Bergen, M J	Oxygen- and Sr-isotope systematics of the Banda Arc volcanics (Indonesia): Evidence for subductionof continental material

13d. Mafic-ultramafic rocks and complexes

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14. Mantle development in space and time

14a. Experimental constraints on melting in the mantle

See section 13*a*

14b. Source regions, extraction and evolution of basaltic melts

See section 13*b*

14c. Mantle mineralogy and the transition zone.

See section 2*c*

14d. Large scale mantle to terrestrial geochemistry

Blichert-Toft, J, Luais, B	The lifetimes of ancient chemical heterogenities in the mantle and their implications for the evolution of mantle convection.
Carmichael, I	Basic magmas vary by eight orders of magnitude in oxygen fugacity: is this range required for their mantle source region?
Chaussidon, M, Marty, B	Boron isotope variations in OIB and BABB
Chauvel, C, Goldstein, S L, Hofmann, A W	Surface processes control Pb evolution in the mantle
Clayton, R N, Humayun, M	Stable isotope evidence for Earth's raw materials
Crozaz, G	A re-evaluation of the ^{244}Pu chronometer
Dick, H J B, Natland, J, Leg 147 Scientific Party	Melt transport and evolution in the shallow mantle beneath the East Pacific Rise: Preliminary results from ODP Site 895
Galer, S J G	Revised decay energies of potassium, thorium and uranium, and the thermal history of the Earth
Galer, S J G, Laue, H-J, Goldstein, S L, Mezger, K, Hofmann, A W	Concept of a new thermal isotope mass spectrometer
Gilmour, J D, Ash, R D, Turner, G	Iodine-xenon studies of ordinary chondrites using RELAX
Harmon, R S, Hoefs, J	A global analysis of the oxygen isotope composition of basalts: Evidence for low and high ^{18}O reservoirs in the mantle
Harper, C L, Jacobsen, S B	Extinct radionuclide decay signatures and mantle evolution
Hawkesworth, C J, Turner, S	The composition of the sub-continental mantle: evidence from magmatic rocks

Hofmann, A W, Stein, M — Episodic crustal growth and mantle evolution
Jacob, D E, Jagoutz, E, Lowry, D, Mattey, D, Rosenhauer, M, Kudrjavtseva, G P — Diamondiferous eclogites from Udachnaya: a subducted component in the Siberian upper mantle
Jochum, K P, Hofmann, A W — Antimony in mantle-derived rocks: constraints on Earth evolution from moderately siderophile elements
Luais, B — Pb isotope evolution of Archaean granitoids: inferences on world-wide mantle heterogeneity and post-emplacement processes
Mattey, D P, Lowry, D, Macpherson, C G, Chazot, G — Oxygen isotope composition of mantle minerals by laser fluorination analysis: homogeneity in peridotites, heterogeneity in eclogites
Menzies, M A — Plate tectonics and lithosphere architecture: Temporal and spatial consequences
Pearson, D G, Boyd, F R, Hoal, K E O, Hoal, B G, Nixon, P H, Rogers, N W — A Re-Os isotopic and petrological study of Namibian peridotites: contrasting petrogenesis and composition of on- and off-craton lithospheric mantle
Pearson, D G, Snyder, G A, Shirey, S B, Taylor, L A, Sobolev, N — Re-Os isotope evidence for a mid-Archaean age of dimondiferous eclogite xenoliths from the Udachnaya kimberlite, Siberia:
Shirey, S B — Evolution of the Earth's mantle: perspective from the Re-Os isotopic system
Wedepohl, K H — The composition of the continental crust

14e. Rare gases

Allegre, C J, Staudacher, T — Rare gases systematics and mantle structure
Graham, D W — Helium isotope variations along mid-ocean ridges : mantle heterogeneity and melt generation effects
Marty, B, Trull, T, Lussiez, P, Basile, I, Tanguy, J C — Origin and evolution of Mount Etna magmatism: isotope constraints
Moreira, M, Sarda, P, Allegre, C J, Schilling, J-G — Noble gas systematic of Shona Seamount, 52° South Atlantic
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Perez, N M, Wakita, H, Nakai, S, Sano, Y, Williams, S N — $^{3}He/^{4}He$ isotopic ratios in volcanic-hydrothermal discharges from the Canary Islands, Spain: Implications on the origin of the volcanic activity
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14f. Mantle fluids and mantle metasomatism

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Chazot, G, Menzies, M A, Harte, B, Mattey, D — Carbonatite metasomatism and melting of the Arabian lithosphere: Evidence from oxygen isotopes and trace element composition of spinel lherzolites
Deines, P — On the importance of fluids for diamond growth
Mathez, E A, Hunter, R H, Kinzler, R J — Crystallization of the Bushveld Complex and its bearing on melt percolation and metasomatism in the mantle
Minarik, W G, Brenan, J M — Connectivity of volatile-rich melts in mantle source-regions: Constraints from Fe-transport experiments
Odling, N W A — Experimental evidence for the nature of upper mantle metasomatism
Riley, T R, Bailey, D K, Lloyd, F E, Fenwick, C S, Palmer, M R — Carbonate metasomatism in the Eifel (Germany) sub-continental lithosphere: geochemical and isotopic signature

Schiano, P, Clocchiatti, R, Shimizu, N	Melt inclusions trapped in mantle minerals: a clue to identifying metasomatic agents in the upper mantle beneath continental and oceanic intraplate regions
Schrauder, M, Navon, O, Szafranek, D, Kaminsky, F V, Galimov, E M	Fluids in Yakutian and Indian diamonds
Schrauder, M, Koeberl, C	Trace element analyses of fluid-bearing fibrous diamonds from Jwaneng (Botswana) by neutron activation analysis
van der Laan, S R, Foley, S F	MARIDs and mantle metasomatism
Zinngrebe, E, Foley, S	Metasomatism in two natural peridotites: effects of low-aSiO$_2$ melts

14g. Small-scale evidence of geochemical processes in mantle rocks and ultrabasic complexes

Batanova, V G, Sobolev, A V, Schmincke, H-U	Mantle lherzolites from Troodos ophiolites: mineralogy and ion probe geochemistry of clinopyroxenes
Graham, C M, Kinny, P D, Harte, B, Valley, J M	The nature and scale of stable isotope disequilibrium in the mantle: Ion and laser microprobe evidence
Lowry, D, Mattey, D P, Macpherson, C G, Harris, J W	Evidence for stable isotope and chemical disequilibrium associated with diamond formation in the mantle
Rampone, E, Piccardo, G B, Vannucci, R, Bottazzi, P, Zanetti, A	Melt impregnation in ophiolitic peridotites: an ion microprobe study of clinopyroxene and plagioclase
Shimizu, N	Chemical zoning of garnets in peridotites and diamonds
Takazawa, E, Shimizu, N, Frey, F A	Development and evolution of the lithospheric mantle: a case study from the Horoman peridotite, Japan
Tribuzio, R, Vannucci, R, Bottazzi, P, Ottolini, L	Residence of REE in low-temperature eclogites from Ligurian Alps, north western Italy: the role of accessory minerals
Vannucci, R, Bottazzi, P, Ottolini, L, Dal Negro, A, Piccirillo, E M	The trace element variations in clinopyroxenes from spinel peridotite xenoliths from western Victoria (Australia)
Witt-Eickschen, G, Kaminsky, W, Harte, B, Seck, H A	Trace element concentrations in amphibole and/or clinopyroxene from composite mantle xenoliths of the West Eifel (Germany): an ion-microprobe study
Zanetti, A, Vannucci, R, Bottazzi, P, Oberti, R, Ottolini, L	Crystal-chemical variations in amphiboles close to a hornblendite vein: implications for models of mantle metasomatism

14h. Mafic-ultramafic rocks and complexes

Becker, H	Geochemistry of high-temperature garnet peridotite complexes from Lower Austria (Southern Bohemian Massif): Crustal signatures in the lower lithosphere
Cocherie, A, Rossi, P	Characterization and evolution of mafic magmatism in the late orogenic Variscan batholith of Corsica
Essawy, M A, El-Metwally, A A	Pan African mafic-ultramafic cumulate intrusions SW Sinai Massif: mineralogy, geochemistry and crustal growth
Frick, L R, Lambert, D D, Reeves, S J, Heaman, L M	Platinum group element and osmium isotope evidence for the origin of Scourie dykes
Jordaan, L J, Scheepers, R, Barton, E S	The correlation between the isotope distribution and geochemistry of mafic to intermediate igneous rocks from the South African West Coast
Lahtinen, R	Preliminary notes on the geochemical characteristics of mantle during 1.93–1.79 Ga beneath the Svecofennian domain, Finland

Lahtinen, R, Lestinen, P, Korkiakoski, E, Salminen,, R, Sanstrom, H, Savolainen, H, Vallius, H — Rock geochemistry research project (RGRP) in the Geological Survey of Finland

Leelanandam, C — The Kondapalli layered complex, Andhra Pradesh, India: Geology, mineralogy and chemistry

Lu, M, Hofmann, A W, Rivalenti, R, Mazzucchelli, M — Geochemistry of the lower crustal mafic-ultramafic complex at Finero, Ivrea Zone, N Italy

McDonald, I, de Wit, M J, Bizzi, L A — The geochemistry of the platinum-group elements in kimberlites and the nature of the PGE in the subcratonic lithospheric mantle

Meisel, T, Biino, G G, Nagler, T — Os and Sm/Nd isotopic constraints on ultramafic petrogenesis in the Helvetic basement

Nagler, T F, Frei, R — A combined U-Pb-zircon, Pb-Pb-Nd isotope investigation on the Masirah ophiolite, Oman: Indications for generation of acidic rocks by pure differentiation of a depleted mantle source

Pudlo, D, Franz, G — Magma generation in a deep seated magma chamber - evidence by mineral-, geochemical, and isotope data from Pan-African dyke rocks (Bir Safsaf/SW Egypt)

Ramo, O T, Boyd, W W, Vaasjoki, M, Cameron, R L, Ryckman, D A — 1.3 Ga mafic magmatism of the St Francois mountains area of SE Missouri

Schaaf, P, Heinrich, W — Geochemical, Sr-Nd isotopic, and P-T data on a Central Mexican xenolith suite: Evidence for upper mantle and lower crust compositions

Van Baalen, M R — Metapyroxenites from New Idria, California, USA

Wai, K M, Abbot, M J, Grady, A E — The Sadowa igneous complex, Eastern Papua New Guinea: Ophiolite or not?

15. Geochronometry and thermal history

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Effects of water content, temperature and pressure on actinide tracer diffusion in melts of haplogranitic composition

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Introduction

An understanding of the rates and mechanisms of U and Th diffusion in silicate melts and glasses is necessary to fully understand such diverse phenomena as U-Th decay series disequilibria, melt-crystal partitioning, and leaching of actinides from nuclear waste glasses. Uranium diffusivities have been determined in anhydrous borosilicate nuclear waste glasses (Dunn, 1987), and numerous investigators have studied release rates of actinides during leaching of glass by hydrothermal solutions (e.g. Schreiber *et al.*, 1985). Dissolved water is known to enhance diffusion of other high field strength elements in silicate melts (e.g. Harrison and Watson, 1983). In light of the abundance of water in felsic silicate melts, and the prevalence of water-rich compositions in ancient weathered natural glasses (Mungall and Martin 1994), we have investigated the effects of water content and temperature on U and Th diffusion rates in a synthetic haplogranite composition at pressures ranging from one atmosphere to 10 kbars.

Experiments

Two batches of bubble-free, homogeneous glass (one clean HPG-8 (see Holz *et al.*, 1992 for composition), the other doped with 0.1% each of U and Th) were prepared by fusing oxide and carbonate powders in a Pt crucible at 1600°C, stirring for several days with a Pt spindle, and cooling in air. For one-atmosphere anhydrous experiments, the glass was drilled and sliced into 8 mm-diameter discs 2 mm thick with polished ends. Diffusion couples were made by juxtaposing the two glasses in a Pt capsule. For high pressure experiments the clean glass was ground and tamped into Pt cylinders; in water-bearing runs double distilled water was added to give 4.5 wt. % water, after which doped glass powder was poured in, tamped, and the cylinder was welded shut. One atmosphere experiments were conducted in a box furnace; high pressure experiments were conducted in a 1/2" piston-cylinder apparatus with alumina pressure medium. One atmosphere experiments were quenched by removing from the furnace, whereas high pressure experiments were quenched by turning off the furnace. Run products were sectioned and polished for analysis on a Cameca WDS microprobe at 25 kV accelerating voltage and 100 nA probe current, with a defocussed beam. Most traverses were 1 to 3 mm wide; if the flat extremes of the diffusion profile were not at least 500 μm wide the experiment was discarded. Because there is no variation in the matrix through the couple, data were collected and processed as raw X-ray counts at 1 to 7 (usually 5) micron point spacings.

Results

Profiles were fit to an error function to minimize chi^2; all the products used had infinite couple geometry and to show no compositional dependence, i.e., the estimated diffusion coefficients are assumed to approximate tracer diffusion coefficients. Uncertainty was estimated by finding the range of values of D within which chi^2 gave 95% confidence of an insignificant residual. The variation of D_U and D_{Th} with temperature, water content and pressure is shown in Fig. 1 for all experiments. The logarithms of both U and Th diffusivities are linear against reciprocal temperature, and are given by the following Arrhenius relationships:

$$D_U = 7.94 \times 10^{-3} \exp\{260 \text{ kJ mol}^{-1}/RT\} \text{ dry, 1 bar}$$
$$D_{Th} = 1.92 \times 10^{-1} \exp\{318 \text{ kJ mol}^{-1}/RT\} \text{ dry, 1 bar}$$
$$D_U = D_{Th} = 9.25 \times 10^{-1} \exp\{239 \text{ kJ mol}^{-1}/RT\}$$
$$4.5 \text{ \% } H_2O, \text{ 10 kbar (Eyring)}$$

These lines are shown in Fig. 1; also shown are the diffusivities predicted by the Eyring equation $D = kT/\zeta\lambda$ (using viscosity ζ from Shaw (1972) at 10 kbar, measured viscosities from Dingwell *et al.* (1992) at 1 bar; jump distance λ = 2.3 Å; k = Boltzmann's constant). The relation we have chosen for D_U and D_{Th} in hydrous melts at 10 kbar is that predicted by the Eyring equation, because regressed lines do not differ significantly

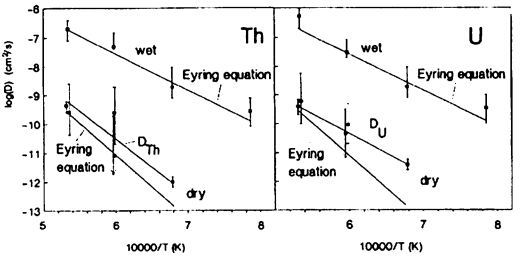

FIG. 1.

from it. This correspondence probably indicates that U and Th diffusion are controlled by the same thermally activated processes that control viscosity. Th is moderately well predicted by the Eyring equation in the anhydrous melts. However, the difference in activation energy of D_U from that of D_{Th} and viscous flow at 1 bar may indicate decoupling of D_U from melt viscosity (transition to intrinsic diffusivity). This observation suggests that U diffusivities at the low temperatures relevant to nuclear waste leaching could be very much higher than equations 2) and 4) suggest. The inference of decoupling hinges on only one measurement at 1200°C; further work will test this possibility with experiments at lower temperatures.

Oxygen fugacity was invoked by Dunn (1987) as a major control on the diffusivity of U in borosilicate glass. In our experiments, oxygen fugacity ranged from 0.21 in the 1 bar experiments to lower values presumed to lie near NNO in the 10 kbar experiments (unbuffered). Over this range in oxgen fugacities U is expected to change from a hexavalent state (uranyl ion UO_2^{2+}) at high f_{O_2} to a mix of pentavalent and quadrivalent ions at lower f_{O_2}; this change may be responsible for the apparent transition from extrinsic to intrinsic diffusion between 10 kbar and 1 bar, since uranyl ion has a much lower charge density than do U^{4+} and U^{5+}. An alternative explanation is that at low water contents (high viscosity) we are observing the intrinsic diffusivity of U whereas at high water contents (low viscosity) the increased mobility of network formers overtakes the intrinsic diffusivity, resulting in Eyring behaviour. An interesting consequence of this hypothesis is that as a magma cools and degasses the diffusivities of U and Th may progress from being subequal to showing differences of several orders of magnitude.

The data show that isotopic decoupling of U and Th decay series by differences in diffusivity are not expected in hydrous silicic melts over a very wide range of temperatures, pressures and water contents, but that at magmatic temperatures in water-poor magmas transport of U may be significantly faster than that of Th, resulting in a potential for U–Th fractionation.

In a reconaissance experiment at 1400°C, 10 kbar, dry, the estimated diffusivities of both U and Th are not significantly different from those calculated at the same temperature for the 1 bar experiment. The apparent slight offset to higher values may result from the diminished melt viscosity at higher pressure, but confirmation of this suggestion would require further work.

Conclusion

Diffusion of U and Th in haplogranitic melt is Arrhenian over the temperature range 1000 to 1600°C, with diffusivities in water-rich melts predicted by the Eyring equation. At high oxygen fugacities and low water contents the diffusion of Th may remain coupled to melt viscosity, but U diffusion appears to be intrinsic, with diffusivity one to two orders of magnitude faster than the predicted Eyring diffusivity at 1200°C. U and Th may therefore become fractionated by transport processes under these conditions. Clarification of the effects of pressure and f_{O_2} over a wider range of temperatures is presently under way.

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