

- Farquhar J, Peters M, Johnston DT, Strauss H, Masterson A, Wiechert LI, Kaufman AJ (2007) Isotopic evidence for Mesoarchean anoxia and changing atmospheric sulfur chemistry. *Nature* 449: 706–710
- Farrell JW, Pedersen TF, Calvert SE, Nielsen B (1995) Glacial-interglacial changes in nutrient utilization in the equatorial Pacific Ocean. *Nature* 377: 514–517
- Ferry JM (1992) Regional metamorphism of the Waits River Formation: delineation of a new type of giant hydrothermal system. *J Petrol* 33: 45–94
- Ferry JM, Dipple GM (1992) Models for coupled fluid flow, mineral reaction and isotopic alteration during contact metamorphism: the Notch Peak aureole, Utah. *Am Miner* 77: 577–591
- Fiebig J, Hoefs J (2002) Hydrothermal alteration of biotite and plagioclase as inferred from intra-granular oxygen isotope- and cation-distribution patterns. *Eur J Miner* 14: 49–60
- Fiebig J, Wiechert U, Rumble D, Hoefs J (1999) High-precision in-situ oxygen isotope analysis of quartz using an ArF laser. *Geochim Cosmochim Acta* 63: 687–702
- Fiebig J, Chiodini G, Caliro S, Rizzo A, Spangenberg J, Hunziker JC (2004) Chemical and isotopic equilibrium between CO<sub>2</sub> and CH<sub>4</sub> in fumarolic gas discharges: generation of CH<sub>4</sub> in arc magmatic-hydrothermal systems. *Geochim Cosmochim Acta* 68: 2321–2334
- Fiebig J, Woodland AB, Spangenberg J, Oschmann W (2007) Natural evidence for rapid abiogenic hydrothermal generation of CH<sub>4</sub>. *Geochim Cosmochim Acta* 71: 3028–3039
- Field CW, Gustafson LB (1976) Sulfur isotopes in the porphyry copper deposit at El Salvador, Chile. *Econ Geol* 71: 1533–1548
- Fiorentini E, Hoernes S, Hoffbauer R, Vitanage PW (1990) Nature and scale of fluid-rock exchange in granulite-grade rocks of Sri Lanka: a stable isotope study. In: D. Vielzeuf, Ph. Vidal (eds.) *Granulites and crustal evolution*. Kluwer, Dordrecht, p. 311–338
- Fischer TP, Giggenbach WF, Sano Y, Williams SN (1998) Fluxes and sources of volatiles discharged from Kudryavy, a subduction zone volcano, Kurile Islands. *Earth Planet Sci Lett* 160: 81–96
- Fischer TP, Hilton DR, Zimmer MM, Shaw AM, Sharp ZD, Walker JA (2002) Subduction and recycling of nitrogen along the Central American margin. *Science* 297: 1154–1157
- Fitzsimons ICW, Harte B, Clark RM (2000) SIMS stable isotope measurement: counting statistics and analytical precision. *Min Mag* 64: 59–83
- Fogel ML, Cifuentes LA (1993) Isotope fractionation during primary production. In: *Organic Geochemistry*, ed. by MH Engel, SA Macko, Plenum Press, New York, p. 73–98
- Foucher D, Hintelmann H (2006) High-precision measurement of mercury isotope ratios in sediments using cold-vapor generation multi-collector inductively coupled plasma mass spectrometry. *Anal Bioanal Chem* 384: 1470–1478
- Foustoukous D, Seyfried WE (2004) Hydrocarbons in vent fluids: the role of chromium catalysts. *Science* 304: 1002–1005
- Francey RJ, Tans PP (1987) Latitudinal variation in oxygen-18 of atmospheric CO<sub>2</sub>. *Nature* 327: 495–497
- Franchi IA, Wright IP, Sexton AS, Pillinger T (1999) The oxygen isotopic composition of Earth and Mars. *Meteorit Planet Sci* 34: 657–661
- Frape SK, Fritz P (1987) Geochemical trends from groundwaters from the Canadian Shield. In: P. Fritz, SK Frape (eds.) *Saline water and gases in crystalline rocks*. Geol Ass Canada Spec Paper 33: 19–38
- Frape SK, Fritz P, McNutt RH (1984) Water-rock interaction and chemistry of groundwaters from the Canadian Shield. *Geochim Cosmochim Acta* 48: 1617–1627
- Freeman KH (2001) Isotopic biogeochemistry of marine organic carbon. *Rev Miner Geochem* 43: 579–605
- Freeman KH, Hayes JM (1992) Fractionation of carbon isotopes by phytoplankton and estimates of ancient CO<sub>2</sub> levels. *Global Biogeochem Cycles* 6: 185–198
- Freeman KH, Hayes JM, Trendel JM, Albrecht P (1990) Evidence from carbon isotope measurements for diverse origins of sedimentary hydrocarbons. *Nature* 343: 254–256
- Freyer HD (1979) On the <sup>13</sup>C-record in tree rings. I. <sup>13</sup>C variations in northern hemisphere trees during the last 150 years. *Tellus* 31: 124–137

- Freyer HD, Belacy N (1983)  $^{13}\text{C}/^{12}\text{C}$  records in northern hemispheric trees during the past 500 years - anthropogenic impact and climatic superpositions. *J Geophys Res* 88: 6844–6852
- Fricke HC, O'Neil JR (1999) The correlation between  $^{18}\text{O}/^{16}\text{O}$  ratios of meteoric water and surface temperature: its use in investigating terrestrial climate change over geologic time. *Earth Planet Sci Lett* 170: 181–196
- Fricke HC, Wickham SM, O'Neil JR (1992) Oxygen and hydrogen isotope evidence for meteoric water infiltration during mylonitization and uplift in the Ruby Mountains - East Humboldt Range core complex, Nevada. *Contr Miner Petrol* 111: 203–221
- Fricke HC, Clyde WC, O'Neil JR (1998a) Intra-tooth variations in  $\delta^{18}\text{O}(\text{PO}_4)$  of mammalian tooth enamel as a record of seasonal variations in continental climate variables. *Geochim Cosmochim Acta* 62: 1839–1850
- Fricke HC, Clyde WC, O'Neil JR, Gingerich PD (1998b) Evidence for rapid climate change in North America during the latest Paleocene thermal maximum: oxygen isotope compositions of biogenic phosphate from the Bighorn Basin (Wyoming). *Earth Planet Sci Lett* 160: 193–208
- Friedman I (1953) Deuterium content of natural waters and other substances. *Geochim Cosmochim Acta* 4: 89–103
- Friedman I, O'Neil JR (1977) Compilation of stable isotope fractionation factors of geochemical interest. In: *Data Geochem*, 6th ed Geol Surv Prof Pap 440KK
- Friedman I, Scholz TG (1974) Isotopic composition of atmospheric hydrogen (1967–1969). *J Geophys Res* 79: 785–788
- Fritz P, Basharnel GM, Drimmie RJ, Ibsen J, Qureshi RM (1989) Oxygen isotope exchange between sulphate and water during bacterial reduction of sulphate. *Chem Geol* 79: 99–105
- Fry B (1988) Food web structure on Georges Bank from stable C, N and S isotopic compositions. *Limnol Oceanogr* 3: 1182–1190
- Fu Q, Sherwood Lollar B, Horita J, Lacrampe-Couloume G, Seyfried WE (2007) Abiotic formation of hydrocarbons under hydrothermal conditions: constraints from chemical and isotope data. *Geochim Cosmochim Acta* 71: 1982–1998
- Gagan MK, Ayliffe LK, Beck JW, Cole JE, Druffel ER, Schrag DP (2000) New views of tropical paleoclimates from corals. *Q Sci Rev* 19: 45–64
- Galimov EM (1985a) The biological fractionation of isotopes. Academic Press, London
- Galimov EM (1985b) The relation between formation conditions and variations in isotope compositions of diamonds. *Geochem Int* 22, 1: 118–141
- Galimov EM (1988) Sources and mechanisms of formation of gaseous hydrocarbons in sedimentary rocks. *Chem Geol* 71: 77–95
- Galimov EM (1991) Isotopic fractionation related to kimberlite magmatism and diamond formation. *Geochim Cosmochim Acta* 55: 1697–1708
- Galimov EM (2006) Isotope organic geochemistry. *Org Geochem* 37: 1200–1262
- Galy A, Belshaw NS, Halicz L, O'Nions RK (2001) High-precision measurement of magnesium isotopes by multiple-collector inductively coupled plasma mass spectrometry. *Inter J Mass Spectr* 208: 89–98
- Galy A, Bar-Matthews M, Halicz L, O'Nions RK (2002) Mg isotopic composition of carbonate: insight from speleothem formation. *Earth Planet Sci Lett* 201: 105–115
- Gao YQ, Marcus RA (2001) Strange and unconventional isotope effects in ozone formation. *Science* 293: 259–263
- Gao X, Thiemens MH (1993a) Isotopic composition and concentration of sulfur in carbonaceous chondrites. *Geochim Cosmochim Acta* 57: 3159–3169
- Gao X, Thiemens MH (1993b) Variations of the isotopic composition of sulfur in enstatite and ordinary chondrites. *Geochim Cosmochim Acta* 57: 3171–3176
- Gao Y, Hoefs J, Przybilla R, Snow JE (2006) A complete oxygen isotope profile through the lower oceanic crust, ODP hole 735B. *Chem Geol* 233: 217–234
- Garlick GD (1966) Oxygen isotope fractionation in igneous rocks. *Earth Planet Sci Lett* 1: 361–368
- Garlick GD, Epstein S (1967) Oxygen isotope ratios in coexisting minerals of regionally metamorphosed rocks. *Geochim Cosmochim Acta* 31: 181

- Gat JR (1971) Comments on the stable isotope method in regional groundwater investigation. *Water Resource Res* 7: 980
- Gat JR (1984) The stable isotope composition of Dead Sea waters. *Earth Planet Sci Lett* 71: 361–376
- Gat JR, Issar A (1974) Desert isotope hydrology: water sources of the Sinai desert. *Geochim Cosmochim Acta* 38: 1117–11131
- Gehre M, Hoefling R, Kowski P, Strauch G (1996) Sample preparation device for quantitative hydrogen isotope analysis using chromium metal. *Anal Chem* 68: 4414–4417
- Gelabert A, Pokrovsky OS, Viers J, Schott J, Boudou A, Feurtet-Mazel A (2006) Interaction between zinc and marine diatom species: surface complexation and Zn isotope fractionation. *Geochim Cosmochim Acta* 70: 839–857
- Georg RB, Reynolds BC, Frank M, Halliday AN (2006) Mechanisms controlling the silicon isotopic compositions of river water. *Earth Planetary Sci Lett* 249: 290–306
- Gerdes ML, Baumgartner LP, Person M, Rumble D (1995) One- and two-dimensional models of fluid flow and stable isotope exchange at an outcrop in the Adamello contact aureole, Southern Alps, Italy. *Am Miner* 80: 1004–1019
- Gerlach TM, Taylor BE (1990) Carbon isotope constraints on degassing of carbon dioxide from Kilauea volcano. *Geochim Cosmochim Acta* 54: 2051–2058
- Gerlach TM, Thomas DM (1986) Carbon and sulphur isotopic composition of Kilauea parental magma. *Nature* 319: 480–483
- Ghosh P, et al. (2006)  $^{13}\text{C}$ - $^{18}\text{O}$  bonds in carbonate minerals: a new kind of paleothermometer. *Geochim Cosmochim Acta* 70: 1439–1456
- Giesemann A, Jäger HA, Norman AL, Krouse HR, Brand WA (1994) On-line sulphur isotope determination using an elemental analyzer coupled to a mass spectrometer. *Anal Chem* 66: 2816–2819
- Giggenbach WF (1992) Isotopic shifts in waters from geothermal and volcanic systems along convergent plate boundaries and their origin. *Earth Planet Sci Lett* 113: 495–510
- Giletti BJ (1985) The nature of oxygen transport within minerals in the presence of hydrothermal water and the role of diffusion. *Chem Geol* 53: 197–206
- Giletti BJ (1986) Diffusion effect on oxygen isotope temperatures of slowly cooled igneous and metamorphic rocks. *Earth Planet Sci Lett* 77: 218–228
- Gilg HA (2000) D/H evidence for the timing of kaolinization in Northeast Bavaria, Germany. *Chem Geol* 170: 5–18
- Gilg HA, Taubald H, Struck U (2007) Phosphoric acid fractionation factors for aragonite between 25 and 72°C with implications on aragonite-calcite oxygen isotope fractionations. *Geochim Cosmochim Acta* 71: A323.
- Girard JP, Savin S (1996) Intercrystalline fractionation of oxygen isotopes between hydroxyl and non-hydroxyl sites in kaolinite measured by thermal dehydroxylation and partial fluorination. *Geochim Cosmochim Acta* 60: 469–487
- Given RK, Lohmann KC (1985) Derivation of the original isotopic composition of Permian marine cements. *J Sediment Petrol* 55: 430–439
- Godfrey JD (1962) The deuterium content of hydrous minerals from the East Central Sierra Nevada and Yosemite National Park. *Geochim Cosmochim Acta* 26: 1215–1245
- Goericke R, Fry B (1994) Variations of marine plankton  $\delta^{13}\text{C}$  with latitude, temperature and dissolved  $\text{CO}_2$  in the world ocean. *Global Geochem Cycles* 8: 85–90
- Goldhaber MB, Kaplan IR (1974) The sedimentary sulfur cycle. In: Goldberg EB (ed) *The sea*, vol. 4. Wiley, New York
- Gonfiantini R (1978) Standards for stable isotope measurements in natural compounds. *Nature* 271: 534–536
- Gonfiantini R (1984) Advisory group meeting on stable isotope reference samples for geochemical and hydrological investigations. Rep Director General IAEA Vienna
- Gonfiantini R (1986) Environmental isotopes in lake studies. In: P. Fritz, J. Fontes (eds.) *Handbook of environmental isotope geochemistry*, vol 2. Elsevier, Amsterdam, pp. 112–168

- Grachev AM, Severinghaus JP (2003) Laboratory determination of thermal diffusion constants for  $^{29}\text{N}/^{28}\text{N}_2$  in air at temperatures from  $-60$  to  $0^\circ\text{C}$  for reconstruction of magnitudes of abrupt climate changes using the ice core fossil-air paleothermometer. *Geochim Cosmochim Acta* 67: 345–360
- Grady MM, Pillinger CT (1990) ALH 85085: nitrogen isotope analysis of a highly unusual primitive chondrite. *Earth Planet Sci Lett* 97: 29–40
- Grady MM, Pillinger CT (1993) Acfer 182: search for the location of  $^{15}\text{N}$ -enriched nitrogen. *Earth Planet Sci Lett* 116: 165–180
- Graham CM, Sheppard SMF, Heaton THE (1980) Experimental hydrogen isotope studies. I. Systematics of hydrogen isotope fractionation in the systems epidote- $\text{H}_2\text{O}$ , zoisite- $\text{H}_2\text{O}$  and  $\text{AlO}(\text{OH})$ - $\text{H}_2\text{O}$ . *Geochim Cosmochim Acta* 44: 353–364
- Graham CM, Harmon RS, Sheppard SMF (1984) Experimental hydrogen isotope studies: hydrogen isotope exchange between amphibole and water. *Am Miner* 69: 128–138
- Graham S, Pearson N, Jackson S, Griffin W, O'Reilly SY (2004) Tracing Cu and Fe from source to porphyry: in situ determination of Cu and Fe isotope ratios in sulfides from the Grasberg Cu-Au deposit. *Chem Geol* 207: 147–169
- Green GR, Ohmoto D, Date J, Takahashi T (1983) Whole-rock oxygen isotope distribution in the Fukazawa-Kosaka Area, Hokuroko District, Japan and its potential application to mineral exploration. *Econ Geol Monogr* 5: 395–411
- Greenwood JP, Riciputi LR, McSween HY (1997) Sulfide isotopic compositions in shergottites and ALH 84001, and possible implications for life on Mars. *Geochim Cosmochim Acta* 61: 4449–4453
- Greenwood RC, Franchi IA, Jambon A, Barrat JA, Burbine TH (2006) Oxygen isotope variation in stony-iron meteorites. *Science* 313: 1763–1765
- Gregory RT, Taylor HP (1981) An oxygen isotope profile in a section of Cretaceous oceanic crust, Samail Ophiolite, Oman: evidence for  $\delta^{18}\text{O}$  buffering of the oceans by deep ( $>5$  km) seawater-hydrothermal circulation at Mid-Ocean Ridges. *J Geophys Res* 86: 2737–2755
- Gregory RT, Taylor HP (1986) Possible non-equilibrium oxygen isotope effects in mantle nodules, an alternative to the Kyser-O'Neil-Carmichael  $^{18}\text{O}/^{16}\text{O}$  geothermometer. *Contr Miner Petrol* 93: 114–119
- Gregory RT, Criss RE, Taylor HP (1989) Oxygen isotope exchange kinetics of mineral pairs in closed and open systems: applications to problems of hydrothermal alteration of igneous rocks and Precambrian Iron Formations. *Chem Geol* 75: 1–42
- Griffith EM, Paytan A, Kozdon R, Eisenhauer A, Ravelo AC (2008) Influences on the fractionation of calcium isotopes in planktonic foraminifera. *Earth Planet Sci Lett* 268: 124–136
- Groote PM, Stuiver M, White JWC, Johnsen S, Jouzel J (1993) Comparison of oxygen isotope records from the GISP-2 and GRIP Greenland ice cores. *Nature* 366: 552–554
- Grossman EL (1984) Carbon isotopic fractionation in live benthic foraminifera - comparison with inorganic precipitate studies. *Geochim Cosmochim Acta* 48: 1505–1512
- Grossman EL, Ku TL (1986) Oxygen and carbon isotope fractionation in biogenic aragonite: temperature effects. *Chem Geol* 59: 59–74
- Grottoli AG, Eakin CM (2007) A review of modern coral  $\delta^{18}\text{O}$  and  $\delta^{14}\text{C}$  proxy records. *Earth Sci Rev* 81: 67–91
- Gruber N (1998) Anthropogenic  $\text{CO}_2$  in the Atlantic Ocean. *Global Biogeochem Cycles* 12: 165–191
- Gruber N, et al. (1999) Spatiotemporal patterns of carbon-13 in the global surface oceans and the oceanic Suess effect. *Global Biogeochem Cycles* 13: 307–335
- Gussone N, et al. (2005) Calcium isotope fractionation in calcite and aragonite. *Geochim Cosmochim Acta* 69: 4485–4494
- Gussone N, et al. (2006) Cellular calcium pathways and isotope fractionation in *Emiliania huxleyi*. *Geology* 34: 625–628
- Guy RD, Fogel ML, Berry JA (1993) Photosynthetic fractionation of the stable isotopes of oxygen and carbon. *Plant Phys* 101: 37–47

- Haack U, Hoefs J, Gohn E (1982) Constraints on the origin of Damaran granites by Rb/Sr and  $\delta^{18}\text{O}$  data. *Contrib Miner Petrol* 79: 279–289
- Habicht KS, Canfield DE (1997) Sulfur isotope fractionation during bacterial sulfate reduction in organic-rich sediments. *Geochim Cosmochim Acta* 61: 5351–5361
- Habicht KS, Canfield DE (2001) Isotope fractionation by sulfate-reducing natural populations and the isotopic composition of sulfide in marine sediments. *Geology* 29: 555–558
- Hackley KC, Anderson TF (1986) Sulfur isotopic variations in low-sulfur coals from the Rocky Mountain region. *Geochim Cosmochim Acta* 50: 703–713
- Haendel D, Mühle K, Nitzsche HIM, Stiehl G, Wand U (1986) Isotopic variations of the fixed nitrogen in metamorphic rocks. *Geochim Cosmochim Acta* 50: 749–758
- Hagemann R, Nief G, Roth E (1970) Absolute isotopic scale for deuterium analysis of natural waters. Absolute D/H ratio for SMOW. *Tellus* 22: 712–715
- Haimson M, Knauth LP (1983) Stepwise fluorination—a useful approach for the isotopic analysis of hydrous minerals. *Geochim Cosmochim Acta* 47: 1589–1595
- Halbout J, Robert F, Javoy M (1990) Hydrogen and oxygen isotope compositions in kerogen from the Orgueil meteorite: clues to a solar origin. *Geochim Cosmochim Acta* 54: 1453–1462
- Hamza MS, Epstein S (1980) Oxygen isotope fractionation between oxygen of different sites in hydroxyl-bearing silicate minerals. *Geochim Cosmochim Acta* 44: 173–182
- Harford CL, Sparks RSJ (2001) Recent remobilisation of shallow-level intrusions on Montserrat revealed by hydrogen isotope compositions of amphiboles. *Earth Planet Sci Lett* 185: 285–298
- Harmon RS, Hoefs J (1986) S-isotope relationships in Late Cenozoic destructive plate margin and continental intraplate volcanic rocks. *Terra Cognita* 6: 182
- Harmon RS, Hoefs J (1995) Oxygen isotope heterogeneity of the mantle deduced from global  $^{18}\text{O}$  systematics of basalts from different geotectonic settings. *Contr Miner Petrol* 120: 95–114
- Harmon RS, Hoefs J, Wedepohl KH (1987) Stable isotope (O,H,S) relationships in Tertiary basalts and their mantle xenoliths from the Northern Hessian Depression, W.Germany. *Contr Miner Petrol* 95: 350–369
- Harrison AG, Thode HG (1957a) Kinetic isotope effect in chemical reduction of sulphate. *Faraday Soc Trans* 53: 1648–1651
- Harrison AG, Thode HG (1957b) Mechanism of the bacterial reduction of sulphate from isotope fractionation studies. *Faraday Soc Trans* 54: 84–92
- Harte B, Otter M (1992) Carbon isotope measurements on diamonds. *Chem Geol* 101: 177–183
- Hartmann M, Nielsen H (1969)  $\delta^{34}\text{S}$ -Werte in rezenten Meeressedimenten und ihre Deutung am Beispiel einiger Sedimentprofile aus der westlichen Ostsee. *Geol Rundsch* 58: 621–655
- Hauri EH (2002) SIMS analysis of volatiles in silicate glasses: 2. Isotopes and abundances in Hawaiian melt inclusions. *Chem Geol* 183: 115–141
- Hauri EH, Wang J, Pearson DG, Bulanova GP (2002) Microanalysis of  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$  and N abundances in diamonds by secondary ion mass spectrometry. *Chem Geol* 185: 149–163
- Hawkesworth CJ, Kemp AIS (2006) Using hafnium and oxygen isotopes in zircons to unravel the record of crustal evolution. *Chem Geol* 226: 144–162
- Hayes JM (1983) Practice and principles of isotopic measurements in organic geochemistry. In: *Organic geochemistry of contemporaneous and ancient sediments*, Great Lakes Section, SEPM, Bloomington, pp 51–53
- Hayes JM (1993) Factors controlling  $^{13}\text{C}$  contents of sedimentary organic compounds: principle and evidence. *Mar Geol* 113: 111–125
- Hayes JM (2001) Fractionation of carbon and hydrogen isotopes in biosynthetic processes. In: JW Valley, DR Cole (eds.) *Stable isotope geochemistry*. *Rev Miner Geochem* 43: 225–277
- Hayes JM, Waldbauer JR (2006) The carbon cycle and associated redox processes through time. *Phil Trans R.Soc B* 361: 931–950
- Hayes JM, Kaplan IR, Wedeking KW (1983) Precambrian organic chemistry, preservation of the record. In: JW Schopf (ed.) *Earth's earliest biosphere: Its origin and evolution*, Chapt 5. Princeton University Press, New Jersey, pp. 93–132

- Hayes JM, Popp BN, Takigiku R, Johnson MW (1989) An isotopic study of biogeochemical relationships between carbonates and organic carbon in the Greenhorn Formation. *Geochim Cosmochim Acta* 53: 2961–2972
- Hayes JM, Strauss H, Kaufman AJ (1999) The abundance of  $^{13}\text{C}$  in marine organic matter and isotopic fractionation in the global biogeochemical cycle of carbon during the past 800 Ma. *Chem Geol* 161: 103–125
- Hays JD, Imbrie J, Shackleton NJ (1976) Variations in the earth's orbit: pacemaker of the ice ages. *Science* 194: 943–954
- Hays PD, Grossman EL (1991) Oxygen isotopes in meteoric calcite cements as indicators of continental paleoclimate. *Geology* 19: 441–444
- Heaton THE (1986) Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: a review. *Chem Geol* 59: 87–102
- Hedenquist JW, Lowenstern JB (1994) The role of magmas in the formation of hydrothermal ore deposits. *Nature* 370: 519–527
- Heidenreich JE, Thieme MH (1983) A non-mass-dependent isotope effect in the production of ozone from molecular oxygen. *J Chem Phys* 78: 892–895
- Helman Y, Barkan E, Eisenstadt D, Luz B, Kaplan A (2005) Fractionation of the three stable oxygen isotopes by oxygen producing and consuming reactions in photosynthetic organisms. *Plant Phys* (2005) 2292–2298
- Hemming NG, Hanson GN (1992) Boron isotopic composition in modern marine carbonates. *Geochim Cosmochim Acta* 56: 537–543
- Hendy CH, Wilson AT (1968) Paleoclimatic data from speleothems. *Nature* 219: 48–51
- Heraty LJ, Fuller ME, Huang L, Abrajano T, Sturchio NC (1999) Isotopic fractionation of carbon and chlorine by microbial degradation of dichloromethane. *Org Geochem* 30: 793–799
- Herbel MJ, Johnson TM, Oremland RS, Bullen TD (2000) Fractionation of selenium isotopes during bacterial respiratory reduction of selenium oxyanions. *Geochim Cosmochim Acta* 64: 3701–3710
- Hervig RL, Moore GM, Williams LB, Peacock SM, Holloway JR, Roggensack K (2002) Isotopic and elemental partitioning of boron between hydrous fluid and silicate melt. *Am Miner* 87: 769–774
- Hesse R, Egeberg PK, Frape SK (2006) Chlorine stable isotope ratios as tracer for pore-water advection rates in a submarine gas-hydrate field: implication for hydrate concentration. *Geofluids* 6: 1–7
- Hesterberg R, Siegenthaler U (1991) Production and stable isotopic composition of  $\text{CO}_2$  in a soil near Bern, Switzerland. *Tellus* 43: 197–205
- Hinrichs KU, Hayes JM, Sylva SP, Brewer PG, DeLong EF (1999) Methane-consuming archaeobacteria in marine sediments. *Nature* 398: 802–805
- Hippler D, Eisenhauer A, Nögler TF (2006) Tropical Atlantic SST history inferred from Ca isotope thermometry over the last 140 ka. *Geochim Cosmochim Acta* 70: 90–100
- Hitchon B, Friedman I (1969) Geochemistry and origin of formation waters in the western Canada sedimentary basin. 1. Stable isotopes of hydrogen and oxygen. *Geochim Cosmochim Acta* 33: 1321–1349
- Hitchon B, Krouse HR (1972) Hydrogeochemistry of the surface waters of the Mackenzie River drainage basin, Canada. III. Stable isotopes of oxygen, carbon and sulfur. *Geochim Cosmochim Acta* 36: 1337–1357
- Hoefs J (1970) Kohlenstoff-und Sauerstoff-Isotopenuntersuchungen an Karbonatkonkretionen und umgebendem Gestein. *Contrib Miner Petrol* 27: 66–79
- Hoefs J (1992) The stable isotope composition of sedimentary iron oxides with special reference to Banded Iron Formations. In: *Isotopic signatures and sedimentary records*. Lecture Notes in Earth Sci 43: 199–213, Springer Verlag, Berlin
- Hoefs J, Emmermann R (1983) The oxygen isotope composition of Hercynian granites and pre-Hercynian gneisses from the Schwarzwald, SW Germany. *Contrib Miner Petrol* 83: 320–329
- Hoefs J, Sywall M (1997) Lithium isotope composition of Quaternary and Tertiary biogenic carbonates and a global lithium isotope balance. *Geochim Cosmochim Acta* 61: 2679–2690



- Hoering TC (1955) Variations in nitrogen-15 abundance in naturally occurring substances. *Science* 122: 1233
- Hoering T, Parker PL (1961) The geochemistry of the stable isotopes of chlorine. *Geochim Cosmochim Acta* 23: 186–199
- Hoernes S, Van Reenen DC (1992) The oxygen isotopic composition of granulites and retrogressed granulites from the Limpopo Belt as a monitor of fluid-rock interaction. *Precambrian Res* 55: 353–364
- Hoffman JH, Hodges RR, McElroy MB, Donahue TM, Kolpin M (1979) Composition and structure of the Venus atmosphere: results from Pioneer Venus. *Science* 205: 49–52
- Hoffman PE, Kaufman AJ, Halverson GP, Schrag DP (1998) Neoproterozoic snowball earth. *Science* 281: 1342–1346
- Holloway JR, Blank JG (1994) Application of experimental results to C-O-H species in natural melts. In: MR Carroll, JR Holloway (eds.) *Volatiles in magmas*. *Rev Miner* 30: 187–230
- Holser WT (1977) Catastrophic chemical events in the history of the ocean. *Nature* 267: 403–408
- Holser WT, Kaplan IR (1966) Isotope geochemistry of sedimentary sulfates. *Chem Geol* 1: 93–135
- Holt BD, Engelkemeier AG (1970) Thermal decomposition of barium sulfate to sulfur dioxide for mass spectrometric analysis. *Anal Chem* 42: 1451–1453
- Hoppe P, Zinner E (2000) Presolar dust grains from meteorites and their stellar sources. *J Geophys Res Space Phys* 105: 10371–10385
- Horita J (1988) Hydrogen isotope analysis of natural waters using an H<sub>2</sub>-water equilibration method: a special implication to brines. *Chem Geol* 72: 89–94
- Horita J (1989) Stable isotope fractionation factors of water in hydrated salt minerals. *Earth Planet Sci Lett* 95: 173–179
- Horita J, Berndt ME (1999) Abiogenic methane formation and isotope fractionation under hydrothermal conditions. *Science* 285: 1055–1057
- Horita J, Wesolowski DJ (1994) Liquid-vapor fractionation of oxygen and hydrogen isotopes of water from the freezing to the critical temperature. *Geochim Cosmochim Acta* 58: 3425–3437
- Horita J, Wesolowski DJ, Cole DR (1993) The activity-composition relationship of oxygen and hydrogen isotopes in aqueous salt solutions. I. Vapor-liquid water equilibration of single salt solutions from 50 to 100°C. *Geochim Cosmochim Acta* 57: 2797–2817
- Horita J, Cole DR, Wesolowski DJ (1995) The activity-composition relationship of oxygen and hydrogen isotopes in aqueous salt solutions: III. Vapor-liquid water equilibration of NaCl solutions to 350°C. *Geochim Cosmochim Acta* 59: 1139–1151
- Horita J, Driesner T, Cole DR (1999) Pressure effect on hydrogen isotope fractionation between brucite and water at elevated temperatures. *Science* 286: 1545–1547
- Horita J, Cole DR, Polyakov VB, Driesner T (2002a) Experimental and theoretical study of pressure effects on hydrous isotope fractionation in the system brucite-water at elevated temperatures. *Geochim Cosmochim Acta* 66: 3769–3788
- Horita J, Zimmermann H, Holland HD (2002b) Chemical evolution of seawater during the Phanerozoic: implications from the record of marine evaporates. *Geochim Cosmochim Acta* 66: 3733–3756
- Hu G, Clayton RN (2003) Oxygen isotope salt effects at high pressure and high temperature and the calibration of oxygen isotope thermometers. *Geochim Cosmochim Acta* 67: 3227–3246
- Hu GX, Rumble D, Wang PL (2003) An ultraviolet laser microprobe for the in-situ analysis of multisulfur isotopes and its use in measuring Archean sulphur isotope mass-independent anomalies. *Geochim Cosmochim Acta* 67: 3101–3118
- Huang L, Struchio NC, Abrajano T, Heraty LJ, Holt BD (1999) Carbon and chlorine isotope fractionation of chlorinated aliphatic hydrocarbons by evaporation. *Org Geochem* 30: 777–785
- Hudson JD (1977) Stable isotopes and limestone lithification. *J Geol Soc London* 133: 637–660
- Huh Y, Chan L-H, Zhang Edmond JM (1998) Lithium and its isotopes in major world rivers; implications for weathering and the oceanic budget. *Geochim Cosmochim Acta* 62: 2039–2051
- Hulston JR (1977) Isotope work applied to geothermal systems at the Institute of Nuclear Sciences, New Zealand. *Geothermics* 5: 89–96

- Hulston JR, Thode HG (1965) Variations in the  $^{33}\text{S}$ ,  $^{34}\text{S}$  and  $^{36}\text{S}$  contents of meteorites and their relations to chemical and nuclear effects. *J Geophys Res* 70: 3475–3484
- Iacumin P, Bocherens H, Mariotti A, Longinelli A (1996) Oxygen isotope analysis of coexisting carbonate and phosphate in biogenic apatite; a way to monitor diagenetic alteration of bone phosphate?. *Earth Planet Sci Lett* 142: 1–6
- Icopini GA, Anbar AD, Ruebush SS, Tien M, Brantley SL (2004) Iron isotope fractionation during microbial reduction of iron: the importance of adsorption. *Geology* 32: 205–208
- Ingraham NL, Criss RE (1998) The effect of vapor pressure on the rate of isotopic exchange between water and vapour. *Chem Geol* 150: 287–292
- Ionov DA, Hoefs J, Wedepohl KH, Wiechert U (1992) Contents and isotopic composition of sulfur in ultramafic xenoliths from Central Asia. *Earth Planet Sci Lett* 111: 269–286
- Irwin H, Curtis C, Coleman M (1977) Isotopic evidence for the source of diagenetic carbonate during burial of organic-rich sediments. *Nature* 269: 209–213
- Ishibashi J, Sano Y, Wakita H, Gamo T, Tsutsumi M, Sakai H (1995) Helium and carbon geochemistry of hydrothermal fluids from the Mid-Okinawa trough back arc basin, southwest of Japan. *Chem Geol* 123: 1–15
- Izbicki JA, Ball JW, Bullen TD, Sutley SJ (2008) Chromium, chromium isotopes and selected trace elements, Western Mojave Desert, USA. *Appl Geochemistry* 23: 1325–1352
- Jaffrés JB, Shields GA, Wallmann K (2007) The oxygen isotope evolution of seawater: a critical review of a long-standing controversy and an improved geological water cycle model for the past 3.4 billion years. *Earth Sci Rev* 83: 83–122
- James DE (1981) The combined use of oxygen and radiogenic isotopes as indicators of crustal contamination. *Ann Rev Earth Planet Sci* 9: 311–344
- James AT (1983) Correlation of natural gas by use of carbon isotopic distribution between hydrocarbon components. *Am Ass Petrol Geol Bull* 67: 1167–1191
- James AT (1990) Correlation of reservoir gases using the carbon isotopic compositions of wet gas components. *Am Ass Petrol Geol Bull* 74: 1441–1458
- James RH, Palmer MR (2000) The lithium isotope composition of international rock standards. *Chem Geol* 166: 319–326
- Jasper JP, Hayes JM (1990) A carbon isotope record of  $\text{CO}_2$  levels during the late Quaternary. *Nature* 347: 462–464
- Jasper JP, Hayes JM, Mix AC, Prahl FG (1994) Photosynthetic fractionation of C-13 and concentrations of dissolved  $\text{CO}_2$  in the central equatorial Pacific. *Paleoceanography* 9: 781–798
- Javoy M, Pineau F, Delorme H (1986) Carbon and nitrogen isotopes in the mantle. *Chem Geol* 57: 41–62
- Jeffcoate AB, Elliott T, Kasemann SA, Ionov D, Cooper K, Brooker R (2007) Li isotope fractionation in peridotites and mafic melts. *Geochim Cosmochim Acta* 71: 202–218
- Jeffrey AW, Pflaum RC, Brooks JM, Sackett WM (1983) Vertical trends in particulate organic carbon  $^{13}\text{C}/^{12}\text{C}$  ratios in the upper water column. *Deep Sea Res* 30: 971–983
- Jenden PD, Kaplan IR, Poreda RJ, Craig H (1988) Origin of nitrogen-rich natural gases in the California Great Valley: evidence from helium, carbon and nitrogen isotope ratios. *Geochim Cosmochim Acta* 52: 851–861
- Jendrzewski N, Eggenkamp HGM, Coleman ML (2001) Characterisation of chlorinated hydrocarbons from chlorine and carbon isotopic compositions: scope of application to environmental problems. *Appl Geochem* 16: 1021–1031
- Jensen ML, Nakai N (1962) Sulfur isotope meteorite standards, results and recommendations. In: Jensen ML (ed) *Biogeochemistry of sulfur isotopes*. NSF Symp Vol, p 31
- Jia Y (2006) Nitrogen isotope fractionations during progressive metamorphism: a case study from the Paleozoic Cooma metasedimentary complex, southeastern Australia. *Geochim Cosmochim Acta* 70: 5201–5214
- Jiang SY, Palmer MR (1998) Boron isotope systematics of tourmaline from granites and tourmalines: a synthesis. *Eur J Miner* 10: 1253–1265



- Jiang J, Clayton RN, Newton RC (1988) Fluids in granulite facies metamorphism: a comparative oxygen isotope study on the South India and Adirondack high grade terrains. *J Geol* 96: 517–533
- Joachimski M, van Geldern R, Breisig S, Buggisch W, Day J (2004) Oxygen isotope evolution of biogenic calcite and apatite during the Middle and Late Devonian. *Int J Earth Sci* 93: 542–553
- Joachimski M, Simon L, van Geldern R, Lecuyer C (2005) Boron isotope geochemistry of Paleozoic brachiopod calcite: implications for a secular change in the boron isotope geochemistry of seawater over the Phanerozoic. *Geochim Cosmochim Acta* 69: 4035–4044
- John SG, Geis RW, Saito MA, Boyle EA (2007a) Zinc isotope fractionation during high-affinity and low-affinity zinc transport by the marine diatom *Thalassiosira oceanica*. *Limnol Oceanogr* 52: 2710–2714
- John SG, Park JG, Zhang Z, Boyle EA (2007b) The isotopic composition of some common forms of anthropogenic zinc. *Chem Geol* 245: 61–69
- John SG, Rouxel OJ, Craddock PR, Engwall AM, Boyle EA (2008) Zinc stable isotopes in seafloor hydrothermal vent fluids and chimneys. *Earth Planet Sci Lett* 269: 17–28
- Johnsen SJ, Clausen HB, Dansgaard W, Gundestrup N, Hammer CU, Tauber H (1995) The Eem stable isotope record along the GRIP ice core and its interpretation. *Quat Res* 43: 117–124
- Johnson TM (2004) A review of mass-dependent fractionation of selenium isotopes and implications for other heavy stable isotopes. *Chem Geol* 204: 201–214
- Johnson CM, Beard BL (2006) Fe isotopes: an emerging technique for understanding modern and ancient biogeochemical cycles. *GSA Today* 16, no 11: 4–10
- Johnson TM, Bullen TD (2003) Selenium isotope fractionation during reduction by Fe(II)-Fe(III) hydroxide-sulfate (green rust). *Geochim Cosmochim Acta* 67: 413–419
- Johnson TM, Herbel MJ, Bullen TD, Zawislanski PT (1999) Selenium isotope ratios as indicators of selenium sources and oxyanion reduction. *Geochim Cosmochim Acta* 63: 2775–2783
- Johnson DG, Jucks KW, Traub WA, Chance KV (2001) Isotopic composition of stratospheric water vapour: measurements and photochemistry. *J Geophys Res* 106: 12211–12217
- Johnson CM, Skulan JL, Beard BL, Sun H, Nealson KH, Braterman PS (2002) Isotopic fraction between Fe(III) and Fe(II) in aqueous solutions. *Earth Planet Sci Lett* 195: 141–153
- Johnson CM, Beard BL, Roden EE (2008) The iron isotope fingerprints of redox and biogeochemical cycling in modern and ancient Earth. *Ann Rev Earth Planet Sci* 36: 457–493
- Johnston DT, Farquhar J, Wing BA, Kaufman AJ, Canfield DE, Habicht KS (2005) Multiple sulfur isotope fractionations in biological systems: a case study with sulphate reducers and sulphur disproportionators. *Am J Sci* 305: 645–660
- Jones HD, Kesler SE, Furman FC, Kyle JR (1996) Sulfur isotope geochemistry of southern Appalachian Mississippi Valley-type depopits. *Econ Geol* 91: 355–367
- Jørgensen BB, Böttcher MA, Lüschen H, Neretin LN, Volkov II (2004) Anaerobic methane oxidation and a deep H<sub>2</sub>S sink generate isotopically heavy sulfides in Black Sea sediments. *Geochim Cosmochim Acta* 68: 2095–2118
- Jouzel J, Merlivat L, Roth E (1975) Isotopic study of hail. *J Geophys Res* 80: 5015–5030
- Jouzel J, Lorius C, Petit JR, Barkov NI, Kotlyakov VM, Petrow VM (1987) Vostok ice core: a continuous isotopic temperature record over the last climatic cycle (160000 years). *Nature* 329: 403–408
- Junk G, Svec H (1958) The absolute abundance of the nitrogen isotopes in the atmosphere and compressed gas from various sources. *Geochim Cosmochim Acta* 14: 234–243
- Kakihana H, Kotaka M, Shohei S, Nomura M, Okamoto N (1977) Fundamental studies on the ion-exchange separation of boron isotopes. *Bull Chem Soc Japan* 50: 158–163
- Kampschulte A, Strauss H (2004) The sulfur isotope evolution of Phanerozoic seawater based on the analyses of structurally substituted sulfate in carbonates. *Chem Geol* 204: 255–280
- Kaplan IR (1975) Stable isotopes as a guide to biogeochemical processes. *Proc R Soc Lond Ser B* 189: 183–211
- Kaplan IR, Hulston JR (1966) The isotopic abundance and content of sulfur in meteorites. *Geochim Cosmochim Acta* 30: 479–496

- Kaplan IR, Rittenberg SC (1964) Microbiological fractionation of sulphur isotopes. *J Gen Microbiol* 34: 195–212
- Kaplan IR, Emery KO, Rittenberg SC (1963) The distribution and isotopic abundance of sulphur in recent marine sediments off Southern California. *Geochim Cosmochim Acta* 27: 297–332
- Kasemann SA, Hawkesworth CJ, Prave AR, Fallick AE, Pearson PN (2005) Boron and calcium isotope composition in Neoproterozoic carbonate rocks from Namibia: evidence for extreme environmental change. *Earth Planet Sci Lett* 231: 73–86
- Kasting JF, Howard MT, Wallmann K, Veizer J, Shields G, Jaffrés J (2006) Paleoclimates, ocean depth and the oxygen isotopic composition of the ocean. *Earth Planet Sci Lett* 252: 82–93
- Kaufman AJ, Knoll GM (1995) Neoproterozoic variations in the C-isotopic composition of seawater: stratigraphic and biogeochemical implications. *Precambrian Res* 73: 27–49
- Kaufmann RS, Long A, Bentley H, Davis S (1984) Natural chlorine isotope variations. *Nature* 309: 338–340
- Kaufmann RS, Long A, Bentley H, Campbell DJ (1986) Chlorine isotope distribution of formation water in Texas and Louisiana. *Bull Am Assoc Petrol Geol* 72: 839–844
- Kaye J (1987) Mechanisms and observations for isotope fractionation of molecular species in planetary atmospheres. *Rev Geophysics* 25: 1609–1658
- Keeling CD (1958) The concentration and isotopic abundance of atmospheric carbon dioxide in rural areas. *Geochim Cosmochim Acta* 13: 322–334
- Keeling CD (1961) The concentration and isotopic abundances of carbon dioxide in rural and marine air. *Geochim Cosmochim Acta* 24: 277–298
- Keeling CD, Mook WG, Tans P (1979) Recent trends in the  $^{13}\text{C}/^{12}\text{C}$  ratio of atmospheric carbon dioxide. *Nature* 277: 121–123
- Keeling CD, Carter AF, Mook WG (1984) Seasonal, latitudinal and secular variations in the abundance and isotopic ratio of atmospheric carbon dioxide. II. Results from oceanographic cruises in the tropical Pacific Ocean. *J Geophys Res* 89: 4615–4628
- Keeling CD, Bacastow RB, Carter AF, Piper SC, Whorf TR, Heimann M, Mook WG, Roeloffzen H (1989) A three dimensional model of atmospheric  $\text{CO}_2$  transport based on observed winds. 1. Analysis of observational data. *Geophys Monogr* 55: 165–236
- Keeling CD, Whorf TP, Wahlen M, van der Plicht J (1995) Interannual extremes in the rate of rise of atmospheric carbon dioxide since 1980. *Nature* 375: 666–670
- Kelley SP, Fallick AE (1990) High precision spatially resolved analysis of  $\delta^{34}\text{S}$  in sulphides using a laser extraction technique. *Geochim Cosmochim Acta* 54: 883–888
- Kelly WC, Rye RO, Livnat A (1986) Saline minewaters of the Keweenaw Peninsula, Northern Michigan: their nature, origin and relation to similar deep waters in Precambrian crystalline rocks of the Canadian Shield. *Am J Sci* 286: 281–308
- Kelly J, Fu B, Kita N, Valley J (2007) Optically continuous silcrete quartz cements in the St. Peter sandstone. *Geochim Cosmochim Acta* 71: 3812–3832
- Kelts K, McKenzie JA (1982) Diagenetic dolomite formation in Quaternary anoxic diatomaceous muds of DSDP Leg 64, Gulf of California. Initial Rep DSDP 64: 553–569
- Kemp ALW, Thode HG (1968) The mechanism of the bacterial reduction of sulphate and of sulphite from isotopic fractionation studies. *Geochim Cosmochim Acta* 32: 71–91
- Kempton PD, Harmon RS (1992) Oxygen isotope evidence for large-scale hybridization of the lower crust during magmatic underplating. *Geochim Cosmochim Acta* 56: 971–986
- Kendall C (1998) Tracing nitrogen sources and cycling in catchments. In: *Isotope Tracers in catchment hydrology*, ed. by C. Kendall, JJ McDonnell, Elsevier Sci p. 519–576
- Kendall C, Grim E (1990) Combustion tube method for measurement of nitrogen isotope ratios using calcium oxide for total removal of carbon dioxide and water. *Anal Chem* 62: 526–529
- Kennicutt MC, Barker C, Brooks JM, De Freitas DA, Zhu GH (1987) Selected organic matter indicators in the Orinoco, Nile and Changjiang deltas. *Org Geochem* 11: 41–51
- Keppler F, Hamilton JTG, Braß M, Röckmann (2006) Methane emissions from terrestrial plants under aerobic conditions. *Nature* 439: 187–191

- Kerrick R, Rehrig W (1987) Fluid motion associated with Tertiary mylonitization and detachment faulting:  $^{18}\text{O}/^{16}\text{O}$  evidence from the Picacho metamorphic core complex, Arizona. *Geology* 15: 58–62
- Kerrick R, Latour TE, Willmore L (1984) Fluid participation in deep fault zones: evidence from geological, geochemical and to  $^{18}\text{O}/^{16}\text{O}$  relations. *J Geophys Res* 89: 4331–4343
- Kerridge JF (1983) Isotopic composition of carbonaceous-chondrite kerogen: evidence for an interstellar origin of organic matter in meteorites. *Earth Planet Sci Lett* 64: 186–200
- Kerridge JF, Haymon RM, Kastner M (1983) Sulfur isotope systematics at the 21°N site, East Pacific Rise. *Earth Planet Sci Lett* 66: 91–100
- Kerridge JF, Chang S, Shipp R (1987) Isotopic characterization of kerogen-like material in the Murchison carbonaceous chondrite. *Geochim Cosmochim Acta* 51: 2527–2540
- Kharaka YK, Berry FAF, Friedman I (1974) Isotopic composition of oil-field brines from Kettleman North Dome, California and their geologic implications. *Geochim Cosmochim Acta* 37: 1899–1908
- Kieffer SW (1982) Thermodynamic and lattice vibrations of minerals: 5. Application to phase equilibria, isotopic fractionation and high-pressure thermodynamic properties. *Rev Geophys Space Phys* 20: 827–849
- Kim KR, Craig H (1990) Two isotope characterization of  $\text{N}_2\text{O}$  in the Pacific Ocean and constraints on its origin in deep water. *Nature* 347: 58–61
- Kim KR, Craig H (1993) Nitrogen-15 and oxygen-18 characteristics of nitrous oxide. *Science* 262: 1855–1858
- Kim ST, O'Neil JR (1997) Equilibrium and nonequilibrium oxygen isotope effects in synthetic carbonates. *Geochim Cosmochim Acta* 61: 3461–3475
- Kim S-T, Mucci A, Taylor BE (2007) Phosphoric acid fractionation factors for calcite and aragonite between 25 and 75°C. *Chem Geol* 246: 135–146
- Kirkley MB, Gurney JJ, Otter ML, Hill SJ, Daniels LR (1991) The application of C-isotope measurements to the identification of the sources of C in diamonds. *Appl Geochem* 6: 477–494
- Kirshenbaum I, Smith JS, Crowell T, Graff J, McKee R (1947) Separation of the nitrogen isotopes by the exchange reaction between ammonia and solutions of ammonium nitrate. *J Chem Phys* 15: 440–446
- Kitchen NE, Valley JW (1995) Carbon isotope thermometry in marbles of the Adirondack Mountains, New York. *J metamorphic Geol* 13: 577–594
- Kiyosu Y, Krouse HR (1990) The role of organic acid in the abiogenic reduction of sulfate and the sulfur isotope effect. *Geochem J* 24: 21–27
- Klochko K, Kaufman AJ, Yao W, Byrne RH, Tossell JA (2006) Experimental measurement of boron isotope fractionation in seawater. *Earth Planet Sci Lett* 248: 276–285
- Kloppmann Girard Négrel P (2002) Exotic stable isotope composition of saline waters and brines from the crystalline basement. *Chem Geol* 184: 49–70
- Knauth LP (1988) Origin and mixing history of brines, Palo Duro Basin, Texas, USA. *Applied Geochemistry* 3: 455–474
- Knauth LP, Beeunas MA (1986) Isotope geochemistry of fluid inclusions in Permian halite with implications for the isotopic history of ocean water and the origin of saline formation waters. *Geochim Cosmochim Acta* 50: 419–433
- Knauth LP, Lowe DR (1978) Oxygen isotope geochemistry of cherts from the Onverwacht group (3.4 billion years), Transvaal, South Africa, with implications for secular variations in the isotopic composition of chert. *Earth Planet Sci Lett* 41: 209–222
- Knoll AH, Hayes JM, Kaufman AJ, Swett K, Lambert IB (1986) Secular variation in carbon isotope ratios from Upper Proterozoic successions of Svalbard and East Greenland. *Nature* 321: 832–838
- Kohn MJ (1996) Predicting animal  $\delta^{18}\text{O}$ : accounting for diet and physiological adaptation. *Geochim Cosmochim Acta* 60: 4811–4829
- Kohn MJ (1999) Why most “dry” rocks should cool “wet”. *Am Miner* 84: 570–580
- Kohn MJ, Cerling TE (2002) Stable isotope compositions of biological apatite. *Rev Miner Geochem* 48: 455–488

- Kohn MJ, Valley JW (1998a) Oxygen isotope geochemistry of amphiboles: isotope effects of cation substitutions in minerals. *Geochim Cosmochim Acta* 62: 1947–1958
- Kohn MJ, Valley JW (1998b) Effects of cation substitutions in garnet and pyroxene on equilibrium oxygen isotope fractionations. *J Metam Geol* 16: 625–639
- Kohn MJ, Valley JW (1998c) Obtaining equilibrium oxygen isotope fractionations from rocks: theory and examples. *Contr Miner Petrol* 132: 209–224
- Kohn MJ, Valley JW (1994) Oxygen isotope constraints on metamorphic fluid flow, Townshend Dam, Vermont, USA. *Geochim Cosmochim Acta* 58: 5551–5566
- Kohn MJ, Valley JW, Elsenheimer D, Spicuzza M (1993) Oxygen isotope zoning in garnet and staurolite: evidence for closed system mineral growth during regional metamorphism. *Am Miner* 78: 988–1001
- Kohn MJ, Schoeninger MJ, Valley JW (1996) Herbivore tooth oxygen isotope compositions: effects of diet and physiology. *Geochim Cosmochim Acta* 60: 3889–3896
- Kohn MJ, Riciputi LR, Stakes D, Orange DL (1998) Sulfur isotope variability in biogenic pyrite: reflections of heterogeneous bacterial colonization? *Am Miner* 83: 1454–1486
- Kolodny Y, Kerridge JF, Kaplan IR (1980) Deuterium in carbonaceous chondrites. *Earth Planet Sci Lett* 46: 149–153
- Kolodny Y, Luz B, Navon O (1983) Oxygen isotope variations in phosphate of biogenic apatites, I. Fish bone apatite - rechecking the rules of the game. *Earth Planet Sci Lett* 64: 393–404
- Kolodny Y, Luz B, Sander M, Clemens WA (1996) Dinosaur bones: fossils or pseudomorphs? The pitfalls of physiology reconstruction from apatitic fossils. *Palaeogeogr Palaeoclimatol Palaeoecol* 126: 161–171
- Krankowsky D, Lämmerzahl P, Mauersberger K (2000) Isotopic measurements of stratospheric ozone. *Geophys Res Lett* 27: 2593–2595
- Krishnamurthy RV, Epstein S, Cronin JR, Pizzarello S, Yuen GU (1992) Isotopic and molecular analyses of hydrocarbons and monocarboxylic acids of the Murchison meteorite. *Geochim Cosmochim Acta* 56: 4045–4058
- Kritee K, Blum JD, Johnson MW, Bergquist BA, Barkay T (2007) Mercury stable isotope fractionation during reduction of Hg(II) to Hg(0) by mercury resistant microorganisms. *Environ Sci Technol* 41: 1889–1895
- Kroopnick P (1985) The distribution of  $^{13}\text{C}$  of  $\Sigma\text{CO}_2$  in the world oceans. *Deep Sea Res* 32: 57–84
- Kroopnick P, Craig H (1972) Atmospheric oxygen: isotopic composition and solubility fractionation. *Science* 175: 54–55
- Kroopnick P, Weiss RF, Craig H (1972) Total  $\text{CO}_2$ ,  $^{13}\text{C}$  and dissolved oxygen- $^{18}\text{O}$  at Geosecs II in the North Atlantic. *Earth Planet Sci Lett* 16: 103–110
- Krouse HR, Case JW (1983) Sulphur isotope abundances in the environment and their relation to long term sour gas flaring, near Valleyview, Alberta. Final Report Res. Management Division, University Alberta RMD Rep 83/18
- Krouse HR, Thode HG (1962) Thermodynamic properties and geochemistry of isotopic compounds of selenium. *Can J Chem* 40: 367–375
- Krouse HR, Viau CA, Eliuk LS, Ueda A, Halas S (1988) Chemical and isotopic evidence of thermochemical sulfate reduction by light hydrocarbon gases in deep carbonate reservoirs. *Nature* 333: 415–419
- Ku TCW, Walter LM, Coleman ML, Blake RE, Martini AM (1999) Coupling between sulfur recycling and syndepositional carbonate dissolution: evidence from oxygen and sulfur isotope composition of pore water sulfate, South Florida Platform, USA. *Geochim Cosmochim Acta* 63: 2529–2546
- Kump LR (1989) Alternative modeling approaches to the geochemical cycles of carbon, sulfur and strontium isotopes. *Am J. Sci* 289: 390–410
- Kump LR (2005) Ironing out biosphere oxidation. *Science* 307: 1058–1059
- Kump LR, Arthur MA (1999) Interpreting carbon-isotope excursions: carbonates and organic matter. *Chem Geol.* 161: 181–198
- Kung CC, Clayton RN (1978) Nitrogen abundances and isotopic compositions in stony meteorites. *Earth Planet Sci Lett* 38: 421–435

- Kvenvolden KA (1995) A review of the geochemistry of methane in natural gas hydrate. *Org Geochem* 23: 997–1008
- Kyser TK, O'Neil JR (1984) Hydrogen isotope systematics of submarine basalts. *Geochim Cosmochim Acta* 48: 2123–2134
- Kyser TK, O'Neil JR, Carmichael ISE (1981) Oxygen isotope thermometry of basic lavas and mantle nodules. *Contrib Miner Petrol* 77: 11–23
- Kyser TK, O'Neil JR, Carmichael ISE (1982) Genetic relations among basic lavas and mantle nodules. *Contrib Miner Petrol* 81: 88–102
- Kyser TK, O'Neil JR, Carmichael ISE (1986) Reply to “Possible non-equilibrium oxygen isotope effects in mantle nodules, an alternative to the Kyser-O'Neil-Carmichael geothermometer. *Contr Miner Petrol* 93: 120–123
- Labeyrie LD, Juillet A (1982) Oxygen isotope exchangeability of diatom valve silica; interpretation and consequences for paleoclimatic studies. *Geochim Cosmochim Acta* 46: 967–975
- Labeyrie LD, Duplessy JC, Blanc PL (1987) Deep water formation and temperature variations over the last 125000 years. *Nature* 327: 477–482
- Land LS (1980) The isotopic and trace element geochemistry of dolomite: the state of the art. In: Concepts and models of dolomitization. *Soc Econ Paleontol Min Spec Publ* 28: 87–110
- Lane GA, Dole M (1956) Fractionation of oxygen isotopes during respiration. *Science* 123: 574–576
- Langer G, Gussone N, Nehrke G, Riebesell U, Eisenhauer A, Thoms S (2007) Calcium isotope fractionation during coccolith formation in *Emiliania huxleyi*: independence of growth and calcification. *Geochem Geophys Geosys* 8: Q05007, doi:10.1029/2006GC001422
- Larson PB, Maher K, Ramos FC, Chang Z, Gaspar M, Meinert LD (2003) Copper isotope ratios in magmatic and hydrothermal ore-forming processes. *Chem Geol* 201: 337–350
- Lawrence JR (1989) The stable isotope geochemistry of deep-sea pore water. In: *Handbook of environmental isotope geochemistry*, vol 3. Elsevier, New York, 317–356
- Lawrence JR, Gieskes JM (1981) Constraints on water transport and alteration in the oceanic crust from the isotopic composition of the pore water. *J Geophys Res* 86: 7924–7934
- Lawrence JR, Taviani M (1988) Extreme hydrogen, oxygen and carbon isotope anomalies in the pore waters and carbonates of the sediments and basalts from the Norwegian Sea: methane and hydrogen from the mantle? *Geochim Cosmochim Acta* 52: 2077–2083
- Lawrence JR, Taylor HP (1971) Deuterium and oxygen-18 correlation: clay minerals and hydroxides in Quaternary soils compared to meteoric waters. *Geochim Cosmochim Acta* 35: 993–1003
- Lawrence JR, White JWC (1991) The elusive climate signal in the isotopic composition of precipitation. In: *Stable Isotope Geochemistry: a tribute to Samuel Epstein*. Special Publication 3, 169–185 The Geochemical Society, USA
- Laws EA, Popp BN, Bidigare RR, Kennicutt MC, Macko SA (1995) Dependence of phytoplankton carbon isotopic composition on growth rate and  $\text{CO}_{2\text{aq}}$ : theoretical considerations and experimental results. *Geochim Cosmochim Acta* 59: 1131–1138
- Laws EA, Bidigare RR, Popp BN (1997) Effect of growth rate and  $\text{CO}_2$  concentration on carbon isotope fractionation by the marine diatom *Phaeodactylum tricornutum*. *Limnol Oceanogr* 42: 1552–1560
- Leclerc AJ, Labeyrie LC (1987) Temperature dependence of oxygen isotopic fractionation between diatom silica and water. *Earth Planet Sci Lett* 84: 69–74
- Lécuyer C, Grandjean P, Reynard B, Albarede F, Telouk P (2002)  $^{11}\text{B}/^{10}\text{B}$  analysis of geological materials by ICP-MS Plasma 54: application to boron fractionation between brachiopod calcite and seawater. *Chem Geol* 186: 45–55
- Leder JL, Swart PK, Szant AM, Dodge RE (1996) The origin of variations in the isotopic record of scleractinian corals: I. Oxygen. *Geochim Cosmochim Acta* 60: 2857–2870
- Leeman WP, Tonarini S, Chan LH, Borg LE (2004) Boron and lithium isotopic variations in a hot subduction zone – the southern Washington Cascades. *Chem Geol* 212: 101–124
- Lehmann M, Siegenthaler U (1991) Equilibrium oxygen- and hydrogen-isotope fractionation between ice and water. *J Glaciology* 37: 23–26

- Lemarchand D, Gaillardet J, Lewin E, Allegre CJ (2000) The influence of rivers on marine boron isotopes and implications for reconstructing past ocean pH. *Nature* 408: 951–954
- Lemarchand D, Gaillardet J, Lewin E, Allegre CJ (2002) Boron isotope systematics in large rivers: implications for the marine boron budget and paleo-pH reconstruction over the Cenozoic. *Chem Geol* 190: 123–140
- Lemarchand D, Wasserburg GJ, Papanastassiou DA (2004) Rate-controlled calcium isotope fractionation in synthetic calcite. *Geochim Cosmochim Acta* 68: 4665–4678
- Leng MJ, Marshall JD (2004) Palaeoclimate interpretation of stable isotope data from lake sediment archives. *Q Sci Rev* 23: 811–831
- Leshin LA, Epstein S, Stolper EM (1996) Hydrogen isotope geochemistry of SNC meteorites. *Geochim Cosmochim Acta* 60: 2635–2650
- Leshin LA, McKeegan KD, Carpenter PK, Harvey RP (1998) Oxygen isotopic constraints on the genesis of carbonates from Martian meteorite ALH 84001. *Geochim Cosmochim Acta* 62: 3–13
- Letolle R (1980) Nitrogen-15 in the natural environment. In: Fritz P, Fontes JCh (eds) *Handbook of environmental isotope geochemistry*. Elsevier, Amsterdam, p 407–433
- Leuenberger M, Siegenthaler U, Langway CC (1992) Carbon isotope composition of atmospheric CO<sub>2</sub> during the last ice age from an Antarctic ice core. *Nature* 357: 488–490
- Lewan MD (1983) Effects of thermal maturation on stable carbon isotopes as determined by hydrous pyrolysis of Woodford shale. *Geochim Cosmochim Acta* 47: 1471–1480
- Lewis RS, Anders E, Wright IP, Norris SJ, Pillinger CT (1983) Isotopically anomalous nitrogen in primitive meteorites. *Nature* 305: 767–771
- Liebscher A, Meixner A, Romer R, Heinrich W (2005) Liquid-vapor fractionation of boron and boron isotopes: experimental calibration at 400°C/23 Mpa to 450°C/42Mpa. *Geochim Cosmochim Acta* 69: 5693–5704
- Liebscher A, Barnes J, Sharp Z (2006) Chlorine isotope vapor-liquid fractionation during experimental fluid-phase separation at 400°C/23 Mpa to 450°C/42Mpa. *Chem Geol* 234: 340–345
- Lister GS, Kelts K, Chen KZ, Yu JQ, Niessen F (1991) Lake Qinghai, China: closed-basin lake levels and the oxygen isotope record for ostracoda since the latest Pleistocene. *Palaeogeogr Palaeoclimatol Palaeoecol* 84: 141–162
- Lloyd MR (1967) Oxygen-18 composition of oceanic sulfate. *Science* 156: 1228–1231
- Lloyd MR (1968) Oxygen isotope behavior in the sulfate-water system. *J Geophys Res* 73: 6099–6110
- Long A, Eastoe CJ, Kaufmann RS, Martin JG, Wirt L, Fincey JB (1993) High precision measurement of chlorine stable isotope ratios. *Geochim Cosmochim Acta* 57: 2907–2912
- Longinelli A (1966) Ratios of oxygen-18: oxygen-16 in phosphate and carbonate from living and fossil marine organisms. *Nature* 211: 923–926
- Longinelli A (1984) Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research?. *Geochim Cosmochim Acta* 48: 385–390
- Longinelli A, Bartelloni M (1978) Atmospheric pollution in Venice, Italy, as indicated by isotopic analyses. *Water Air Soil Poll* 10: 335–341
- Longinelli A, Craig H (1967) Oxygen-18 variations in sulfate ions in sea-water and saline lakes. *Science* 156: 56–59
- Longinelli A, Edmond JM (1983) Isotope geochemistry of the Amazon basin. A reconnaissance. *J Geophys Res* 88: 3703–3717
- Longinelli A, Nuti S (1973) Revised phosphate-water isotopic temperature scale. *Earth Planet Sci Lett* 19: 373–376
- Longstaffe FJ (1989) Stable isotopes as tracers in clastic diagenesis. In: *Short course in burial diagenesis*, ed. IE Hutcheon, Min Ass Canada Short Course Series 15: 201–277
- Longstaffe FJ, Schwarcz HP (1977) <sup>18</sup>O/<sup>16</sup>O of Archean clastic metasedimentary rocks: a petrogenetic indicator for Archean gneisses?. *Geochim Cosmochim Acta* 41: 1303–1312
- Lorius C, Jouzel J, Ritz C, Merlivat L, Barkov NI, Korotkevich YS, Kotlyakov VM (1985) A 150000 year climatic record from Antarctic ice. *Nature* 316: 591–596
- Lücke A, Moschen R, Schleser G (2005) High-temperature carbon reduction of silica: a novel approach for oxygen isotope analysis of biogenic opal. *Geochim Cosmochim Acta* 69: 1423–1433



- Lundstrom CC, Chaussidon M, Hsui AT, Keleman P, Zimmermann M (2005) Observations of Li isotope variations in the Trinity ophiolite: evidence for isotope fractionation by diffusion during mantle melting. *Geochim Cosmochim Acta* 69: 735–751
- Luz B, Barkan E (2000) Assessment of oceanic productivity with the triple-isotope composition of dissolved oxygen. *Science* 288: 2028–2031
- Luz B, Barkan E (2005) The isotopic ratios  $^{17}\text{O}/^{16}\text{O}$  and  $^{18}\text{O}/^{16}\text{O}$  in molecular oxygen and their significance in biogeochemistry. *Geochim Cosmochim Acta* 69: 1099–1110
- Luz B, Barkan E (2007) Excess  $^{17}\text{O}$  – a new tracer in hydrology. *Geochim Cosmochim Acta* 71: A604
- Luz B, Kolodny Y (1985) Oxygen isotope variations in phosphate of biogenic apatites, IV: Mammalian teeth and bones. *Earth Planet Sci Lett* 75: 29–36
- Luz B, Kolodny Y, Horowitz M (1984) Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water. *Geochim Cosmochim Acta* 48: 1689–1693
- Luz B, Cormie AB, Schwarcz HP (1990) Oxygen isotope variations in phosphate of deer bones. *Geochim Cosmochim Acta* 54: 1723–1728
- Luz B, Barkan E, Bender ML, Thieme MH, Boering KA (1999) Triple-isotope composition of atmospheric oxygen as a tracer of biosphere productivity. *Nature* 400: 547–550
- Machel HG, Krouse HR, Sassen P (1995) Products and distinguishing criteria of bacterial and thermochemical sulfate reduction. *Appl Geochemistry* 10: 373–389
- Magenheim AJ, Spivack AJ, Volpe C, Ranson B (1994) Precise determination of stable chlorine isotope ratios in low-concentration natural samples. *Geochim Cosmochim Acta* 58: 3117–3121
- Magenheim AJ, Spivack AJ, Michael PJ, Gieskes JM (1995) Chlorine stable isotope composition of the oceanic crust: implications for earth's distribution of chlorine. *Earth Planet Sci Lett* 131: 427–432
- Magna T, Wiechert U, Halliday AN (2006) New constraints on the lithium isotope composition of the Moon and terrestrial planets. *Earth Planet Sci Lett* 243: 336–353
- Maréchal CN, Albarède F (2002) Ion-exchange fractionation of copper and zinc isotopes. *Geochim Cosmochim Acta* 66: 1499–1509
- Maréchal CN, Télouk P, Albarède F (1999) Precise analysis of copper and zinc isotopic compositions by plasma-source mass spectrometry. *Chem Geol* 156: 251–273
- Maréchal CN, Nicolas E, Douchet C, Albarède F (2000) Abundance of zinc isotopes as a marine biogeochemical tracer. *Geochim Geophys Geosys*  $\text{G}^3$  1 1999GC000029
- Mariotti A, Germon JC, Hubert P, Kaiser P, Letolle R, Tardieux P (1981) Experimental determination of nitrogen kinetic isotope fractionation: some principles, illustration for the denitrification and nitrification processes. *Plant Soil* 62: 413–430
- Markl G, Musashi M, Bucher K (1997) Chlorine stable isotope composition of granulites from Lofoten, Norway: implication for the Cl-isotope composition and for the source of Cl enrichment in the lower crust. *Earth Planet Science Lett* 150: 95–120
- Markl G, Lahaye Y, Schwinn G (2006a) Copper isotopes as monitors of redox processes in hydrothermal mineralization. *Geochim Cosmochim Acta* 70: 4215–4228
- Markl G, von Blanckenburg F, Wagner T (2006b) Iron isotope fractionation during hydrothermal ore deposition and alteration. *Geochim Cosmochim Acta* 70: 3011–3030
- Marowsky G (1969) Schwefel-, Kohlenstoff- und Sauerstoffisotopenuntersuchungen am Kupferschiefer als Beitrag zur genetischen Deutung. *Contrib Miner Petrol* 22: 290–334
- Marschall HR, Altherr R, Kalt A, Ludwig T (2008) Detrital, metamorphic and metasomatic tourmaline in high-pressure metasediments from Syros (Greece): intra-grain boron isotope patterns determined by secondary-ion mass spectrometry. *Contr Miner Petrol* 155: 703–717
- Martinson DG, Pisias NG, Hays JD, Imbrie J, Moore TC, Shackleton NJ (1987) Age dating and the orbital theory of the ice ages: development of a high resolution 0 to 300000 year chronostratigraphy. *Quat Res* 27: 1–29
- Marty B, Humbert F (1997) Nitrogen and argon isotopes in oceanic basalts. *Earth Planet Sci Lett* 152: 101–112

- Marty B, Zimmermann L (1999) Volatiles (He, C, N, Ar) in mid-ocean ridge basalts: assesment of shallow-level fractionation and characterization of source composition. *Geochim Cosmochim Acta* 63: 3619–3633
- Mastalerz M, Schimmelmann A (2002) Isotopically exchangeable organic hydrogen in coal relates to thermal maturity and maceral composition. *Org Geochem* 33: 921–931
- Matheny RK, Knauth LP (1989) Oxygen isotope fractionation between marine biogenic silica and seawater. *Geochim Cosmochim Acta* 53: 3207–3214
- Mathur R, Ruiz J, Titley S, Liermann L, Buss H, Brantley S (2005) Cu isotopic fractionation in the supergene environment with and without bacteria. *Geochim Cosmochim Acta* 69: 5233–5246
- Matsubaya O, Sakai H (1973) Oxygen and hydrogen isotopic study on the water of crystallization of gypsum from the Kuroko-type mineralization. *Geochem J* 7: 153–165
- Matsuhisa Y (1979) Oxygen isotopic compositions of volcanic rocks from the east Japan island arcs and their bearing on petrogenesis. *J Volcanic Geotherm Res* 5: 271–296
- Matsuhisa Y, Goldsmith JR, Clayton RN (1978) Mechanisms of hydrothermal crystallization of quartz at 250°C and 15 kbar. *Geochim Cosmochim Acta* 42: 173–182
- Matsuhisa Y, Goldsmith JR, Clayton RN (1979) Oxygen isotope fractionation in the systems quartz-albite-anorthite-water. *Geochim Cosmochim Acta* 43: 1131–1140
- Matsumoto R (1992) Causes of the oxygen isotopic depletion of interstitial waters from sites 798 and 799, Japan Sea, Leg 128. *Proc of the Ocean Drilling Progr, Scientific Results, Vol 127/128: 697–703*
- Matsuo S, Friedman I, Smith GI (1972) Studies of Quaternary saline lakes. I. Hydrogen isotope fractionation in saline minerals. *Geochim Cosmochim Acta* 36: 427–435
- Mattey DP, Carr RH, Wright IP, Pillinger CT (1984) Carbon isotopes in submarine basalts. *Earth Planet Sci Lett* 70: 196–206
- Mattey DP, Lowry D, MacPherson C (1994) Oxygen isotope composition of mantle peridotites. *Earth Planet Sci Lett* 128: 231–241
- Matthews A, Goldsmith JR, Clayton RN (1983a) Oxygen isotope fractionation involving pyroxenes: the calibration of mineral-pair geothermometers. *Geochim Cosmochim Acta* 47: 631–644
- Matthews A, Goldsmith JR, Clayton RN (1983b) Oxygen isotope fractionation between zoisite and water. *Geochim Cosmochim Acta* 47: 645–654
- Matthews A, Goldsmith JR, Clayton RN (1983c) On the mechanics and kinetics of oxygen isotope exchange in quartz and feldspars at elevated temperatures and pressures. *Geol Soc Am Bull* 94: 396–412
- Mauersberger K (1981) Measurement of heavy ozone in the stratosphere. *Geophys Res Lett* 8: 935–937
- Mauersberger K (1987) Ozone isotope measurements in the stratosphere. *Geophys Res Lett* 14: 80–83
- Mauersberger K, Erbacher B, Krankowsky D, Günther J, Nickel R (1999) Ozone isotope enrichment: isotopomer-specific rate coefficients. *Science* 283: 370–372
- McCaig AM, Wickham SM, Taylor HP (1990) Deep fluid circulation in Alpine shear zones, Pyrenees, France: field and oxygen isotope studies. *Contr Miner Petrol* 106: 41–60
- McCollom TM, Seewald JS (2006) Carbon isotope composition of organic compounds produced by abiotic synthesis under hydrothermal conditions. *Earth Planet Sci Lett* 243: 74–84
- McConnaughey T (1989a)  $^{13}\text{C}$  and  $^{18}\text{O}$  disequilibrium in biological carbonates. I. Patterns. *Geochim Cosmochim Acta* 53: 151–162
- McConnaughey T (1989b)  $^{13}\text{C}$  and  $^{18}\text{O}$  disequilibrium in biological carbonates. II. In vitro simulation of kinetic isotope effects. *Geochim Cosmochim Acta* 53: 163–171
- McCorkle DC, Emerson SR (1988) The relationship between pore water isotopic composition and bottom water oxygen concentration. *Geochim Cosmochim Acta* 52: 1169–1178
- McCorkle DC, Emerson SR, Quay P (1985) Carbon isotopes in marine porewaters. *Earth Planet Sci Lett* 74: 13–26
- McCrea JM (1950) On the isotopic chemistry of carbonates and a paleotemperature scale. *J Chem Phys* 18: 849–857

- McCready RGL (1975) Sulphur isotope fractionation by *Desulfovibrio* and *Desulfotomaculum* species. *Geochim Cosmochim Acta* 39: 1395–1401
- McCready RGL, Kaplan IR, Din GA (1974) Fractionation of sulfur isotopes by the yeast *Saccharomyces cerevisiae*. *Geochim Cosmochim Acta* 38: 1239–1253
- McDermott F (2004) Palaeo-climate reconstruction from stable isotope variations in speleothems: a review. *Q Sci Rev* 23: 901–918
- McGarry S, Bar-Matthews M, Matthews A, Vaks A, Schilman B, Ayalon A (2004) Constraints on hydrological and paleotemperature variations in the eastern Mediterranean region in the last 140 ka given by the  $\delta D$  values of speleothem fluid inclusions. *Quat Sci Rev* 23: 919–934
- McGregor ID, Manton SR (1986) Roberts Victor eclogites: ancient oceanic crust. *J Geophys Res* 91: 14063–14079
- McKay DS, et al. (1996) Search for past life on Mars: possible relic biogenic activity in martian meteorite ALH 84001. *Science* 273: 924–930
- McKeegan KD (1987) Ion microprobe measurements of H, C, O, Mg, and Si isotopic abundances in individual interplanetary dust particles. Ph D Thesis, Washington University, St. Louis, Missouri
- McKeegan KD, Leshin LA (2001) Stable isotope variations in extraterrestrial materials. *Rev Miner Geochem* 43: 279–318
- McKeegan KD, Walker RM, Zinner E (1985) Ion microprobe isotopic measurements of individual interplanetary dust particles. *Geochim Cosmochim Acta* 49: 1971–1987
- McKenzie J (1984) Holocene dolomitization of calcium carbonate sediments from the coastal sabkhas of Abu Dhabi, U.A.E.: a stable isotope study. *J Geol* 89: 185–198
- McKibben MA, Riciputi LR (1998) Sulfur isotopes by ion microprobe. In: *Applications of micro-analytical techniques to understanding mineralizing processes*. *Rev Econ Geol* 7: 121–140
- McManus J, Nägler T, Siebert C, Wheat CG, Hammond D (2002) Oceanic molybdenum isotope fractionation: diagenesis and hydrothermal ridge flank alteration. *Geochim Geophys Geosyst* 3: 1078 doi: 10.1029/2002GC000356
- McManus J, et al. (2006) Molybdenum and uranium geochemistry in continental margin sediments: palaeoproxy potential. *Geochim Cosmochim Acta* 70: 4643–4662
- McMullen CC, Cragg CG, Thode HG (1961) Absolute ratio of  $^{11}\text{B}/^{10}\text{B}$  in Searles Lake borax. *Geochim Cosmochim Acta* 23: 147
- McSween HY, Taylor LA, Stolper EM (1979) Allan Hills 77005: a new meteorite type found in Antarctica. *Science* 204: 1201–1203
- Mekhtiyeva VL, Pankina GR (1968) Isotopic composition of sulfur in aquatic plants and dissolved sulfates. *Geochemistry* 5: 624
- Mekhtiyeva VL, Pankina GR, Gavrilov EY (1976) Distribution and isotopic composition of forms of sulfur in water animals and plants. *Geochem Int* 13: 82
- Melander L (1960) Isotope effects on reaction rates. Ronald, New York
- Melander L, Saunders WH (1980) Reaction rates of isotopic molecules. Wiley and Sons, New York
- Mengel K, Hoefs J (1990) Li -  $\delta^{18}\text{O}$  -  $\text{SiO}_2$  systematics in volcanic rocks and mafic lower crustal xenoliths. *Earth Planet Sci Lett* 101: 42–53
- Merritt DA, Hayes JM (1994) Nitrogen isotopic analyses of individual amino acids by isotope-ratio-monitoring gas chromatography/mass spectrometry. *J Am Soc Mass Spectrom* 5: 387–397
- Meyer C, Wunder B, Meixner A, Romer R, Heinrich W (2008) The boron-isotope partitioning between tourmaline and fluid: an experimental re-investigation. *Contr Miner Petr* 156: 259–267
- Mikaloff-Fletcher SE, et al. (2006) Inverse estimates of anthropogenic  $\text{CO}_2$  uptake, transport and storage by the ocean. *Global Biogeochem Cycles* 20: GB2002; doi:10.1029/2005GB002532
- Milkov AV (2005) Molecular and stable isotope compositions of natural gas hydrates: a revised global dataset and basic interpretations in the context of geological settings. *Org Geochem* 36: 681–702
- Miller MF (2002) Isotopic fractionation and the quantification of  $^{17}\text{O}$  anomalies in the oxygen three-isotope system: an appraisal and geochemical significance. *Geochim Cosmochim Acta* 66: 1881–1889

- Ming T, Anders E, Hoppe P, Zinner E (1989) Meteoritic silicon carbide and its stellar sources, implications for galactic chemical evolution. *Nature* 339: 351–354
- Minigawa M, Wada E (1984) Stepwise enrichments of  $^{15}\text{N}$  along food chains: further evidence and the relation between  $\delta^{15}\text{N}$  and animal age. *Geochim Cosmochim Acta* 48: 1135–1140
- Mizutani Y, Rafter TA (1973) Isotopic behavior of sulfate oxygen in the bacterial reduction of sulfate. *Geochem J* 6: 183–191
- Moldovanyi EP, Lohmann KC (1984) Isotopic and petrographic record of phreatic diagenesis: lower Cretaceous Sligo and Cupido Formations. *J Sediment Petrol* 54: 972–985
- Monson KD, Hayes JM (1982) Carbon isotopic fractionation in the biosynthesis of bacterial fatty acids. Ozonolysis of unsaturated fatty acids as a means of determining the intramolecular distribution of carbon isotopes. *Geochim Cosmochim Acta* 46: 139–149
- Monster J, Anders E, Thode HG (1965)  $^{34}\text{S}/^{32}\text{S}$  ratios for the different forms of sulphur in the Orgueil meteorite and their mode of formation. *Geochim Cosmochim Acta* 29: 773–779
- Monster J, Appel PW, Thode HG, Schidlowski M, Carmichael CW, Bridgwater D (1979) Sulphur isotope studies in early Archean sediments from Isua, West Greenland: implications for the antiquity of bacterial sulfate reduction. *Geochim Cosmochim Acta* 43: 405–413
- Mook WG, Bommerson JC, Stavermann WH (1974) Carbon isotope fractionation between dissolved bicarbonate and gaseous carbon dioxide. *Earth Planet Sci Lett* 22: 169–174
- Mook WG, Koopman M, Carter AF, Keeling CD (1983) Seasonal, latitudinal and secular variations in the abundance and isotopic ratios of atmospheric carbon dioxide. I. Results from land stations. *J Geophys Res* 88: 10915–10933
- Montoya JP, Horrigan SG, McCarthy JJ (1991) Rapid, storm-induced changes in the natural abundance of  $^{15}\text{N}$  in a planktonic ecosystem, Chesapeake Bay, USA. *Geochim Cosmochim Acta* 55: 3627–3638
- Moriguti T, Nakamura E (1998) Across-arc variation of Li-isotopes in lavas and implications for crust /mantle recycling at subduction zones. *Earth Planet Sci Lett* 163: 167–174
- Mossmann JR, Aplin AC, Curtis CD, Coleman ML (1991) Geochemistry of inorganic and organic sulfur in organic-rich sediments from the Peru Margin. *Geochim Cosmochim Acta* 55: 3581–3595
- Muehlenbachs K, Byerly G (1982)  $^{18}\text{O}$  enrichment of silicic magmas caused by crystal fractionation at the Galapagos Spreading Center. *Contr Miner Petrol* 79: 76–79
- Muehlenbachs K, Clayton RN (1972) Oxygen isotope studies of fresh and weathered submarine basalts. *Can J Earth Sci* 9: 471–479
- Muehlenbachs K, Clayton RN (1976) Oxygen isotope composition of the oceanic crust and its bearing on seawater. *J Geophys Res* 81: 4365–4369
- Mulitza S, Duerkoop A, Hale W, Wefer S, Niebler HS (1997) Planktonic foraminifera as recorders of past surface-water stratification. *Geology* 25: 335–338
- Nabelek PI (1991) Stable isotope monitors. In: Contact metamorphism. *Rev Miner* 26: 395–435
- Nabelek PI, Labotka TC (1993) Implications of geochemical fronts in the Notch Peak contact-metamorphic aureole, Utah, USA. *Earth Planet Sci Lett* 119: 539–559
- Nabelek PI, Labotka TC, O'Neil JR, Papike JJ (1984) Contrasting fluid/rock interaction between the Notch Peak granitic intrusion and argillites and limestones in western Utah: evidence from stable isotopes and phase assemblages. *Contr Miner Petrol* 86: 25–43
- Nägler TF, Eisenhauer A, Müller A, Hemleben C, Kramers J (2000) The  $\delta^{44}\text{Ca}$ -temperature calibration on fossil and cultured *Globigerinoides sacculifer*: new tool for reconstruction of past sea surface temperatures. *Geochem Geophys Geosystems* 3: 1 (2000GC000091)
- Nägler TF, Siebert C, Lüschen H, Böttcher ME (2005) Sedimentary Mo isotope records across the Holocene fresh-brackish water transition of the Black Sea. *Chem Geol* 219: 283–295
- Nakano T, Nakamura E (2001) Boron isotope geochemistry of metasedimentary rocks and tourmalines in a subduction zone metamorphic suite. *Phys Earth Planet Inter* 127: 233–252
- Neretin LN, Böttcher ME, Jörgensen BB, Volkov II, Lüschen H, Hilgenfeldt K (2004) Pyritization processes and greigite formation in the advancing sulfidization front in the Upper Pleistocene sediments of the Black Sea. *Geochim Cosmochim Acta* 68: 2081–2094

- Nielsen H (1979) Sulfur isotopes. In: Jager E, Hunziker J (eds.) *Lectures in isotope geology*. Springer, Berlin Heidelberg New York, p. 283–312
- Nielsen H, Ricke W (1964) S-Isotopenverhältnisse von Evaporiten aus Deutschland. Ein Beitrag zur Kenntnis von  $\delta^{34}\text{S}$  im Meerwasser Sulfat. *Geochim Cosmochim Acta* 28: 577–591
- Nielsen SG, et al. (2005) Thallium isotope composition of the upper continental crust and rivers – an investigation of the continental sources of dissolved marine thallium. *Geochim Cosmochim Acta* 69: 2007–2019
- Nielsen SG, Rehkämper M, Norman MD, Halliday AN, Harrison D (2006) Thallium isotopic evidence for ferromanganese sediments in the mantle source of Hawaiian basalts. *Nature* 439: 314–317
- Nielsen SG, Rehkämper M, Brandon AD, Norman MD, Turner S, O'Reilly SY (2007) Thallium isotopes in Iceland and Azores lavas – Implications for the role of altered crust and mantle geochemistry. *Earth Planet Sci Lett* 264: 332–345
- Nier AO (1950) A redetermination of the relative abundances of the isotopes of carbon, nitrogen, oxygen, argon and potassium. *Phys Rev* 77: 789
- Nier AO, Ney EP, Inghram MG (1947) A null method for the comparison of two ion currents in a mass spectrometer. *Rev Sci Instrum* 18: 294
- Niles PB, Leshin LA, Guan Y (2005) Microscale carbon isotope variability in ALH84001 carbonates and a discussion of possible formation environments. *Geochim Cosmochim Acta* 69: 2931–2944
- Nishio Y, Sasaki S, Gamo T, Hiyagon H, Sano Y (1998) Carbon and helium isotope systematics of North Fiji basin basalt glasses: carbon geochemical cycle in the subduction zone. *Earth Planet Sci Lett* 154: 127–138
- Nishio Y, Nakai S, Yamamoto J, Sumino H, Matsumoto T, Prikhod'ko VS, Arai S (2004) Lithium isotope systematics of the mantle derived ultramafic xenoliths: implications for EM1 origin. *Earth Planet Sci Letters* 217: 245–261
- Nitzsche HM, Stiehl G (1984) Untersuchungen zur Isotopenfraktionierung des Stickstoffs in den Systemen Ammonium/Ammoniak und Nitrid/Stickstoff. *ZfI Mitt* 84: 283–291
- Norris RD, Röhl U (1999) Carbon cycling and chronology of climate warming during the Paleocene/Eocene transition. *Nature* 401: 775–778
- Northrop DA, Clayton RN (1966) Oxygen isotope fractionations in systems containing dolomite. *J Geol* 74: 174–196
- Norton D, Taylor HP (1979) Quantitative simulation of the hydrothermal systems of crystallizing magmas on the basis of transport theory and oxygen isotope data: an analysis of the Skaergaard intrusion. *J Petrol* 20: 421–486
- Nriagu JO, Coker RD, Barrie LA (1991) Origin of sulphur in Canadian Arctic haze from isotope measurements. *Nature* 349: 142–145
- Ohmoto H (1972) Systematics of sulfur and carbon isotopes in hydrothermal ore deposits. *Econ Geol* 67: 551–578
- Ohmoto H (1986) Stable isotope geochemistry of ore deposits. *Rev Miner* 16: 491–559
- Ohmoto H, Goldhaber MB (1997) Sulfur and carbon isotopes. In: Barnes HL (ed.) *Geochemistry of hydrothermal ore deposits*, 3rd edn. New York, Wiley, p. 435–486
- Ohmoto H, Rye RO (1979) Isotopes of sulfur and carbon. In: *Geochemistry of hydrothermal ore deposits*, 2nd edn. Holt Rinehart and Winston, New York
- Ohmoto H, Mizukani M, Drummond SE, Eldridge CS, Pisutha-Arnond V, Lenagh TC (1983) Chemical processes of Kuroko formation. *Econ Geol Monogr* 5: 570–604
- Ohmoto H, Kakegawa T, Lowe DR (1993) 3.4 billion year old biogenic pyrites from Barberton, South Africa: sulfur isotope evidence. *Science* 262: 555
- O'Leary MH (1981) Carbon isotope fractionation in plants. *Phytochemistry* 20: 553–567
- O'Leary JA, Eiler JM, Rossman GR (2005) Hydrogen isotope geochemistry of nominally anhydrous minerals. *Geochim Cosmochim Acta* 69: A745
- O'Neil JR (1986) Theoretical and experimental aspects of isotopic fractionation. In: *Stable isotopes in high temperature geological Processes*. *Rev Miner* 16: 1–40

- O'Neil JR, Taylor HP (1967) The oxygen isotope and cation exchange chemistry of feldspars. *Am Miner* 52: 1414–1437
- O'Neil JR, Truesdell AH (1991) Oxygen isotope fractionation studies of solute-water interactions. In: *Stable Isotope Geochemistry: A tribute to Samuel Epstein*. The Geochemical Soc Spec Publ 3: 17–25
- O'Neil JR, Roe J, Reinhard E, Blake RE (1994) A rapid and precise method of oxygen isotope analysis of biogenic phosphate. *Israel J Earth Sci* 43: 203–212
- Ongley JS, Basu AR, Kyser TK (1987) Oxygen isotopes in coexisting garnets, clinopyroxenes and phlogopites of Roberts Victor eclogites: implications for petrogenesis and mantle metasomatism. *Earth Planet Sci Lett* 83: 80–84
- Ono S, Wing BA, Johnston D, Farquhar J, Rumble D (2006) Mass-dependent fractionation of quadruple sulphur isotope system as a new tracer of sulphur biogeochemical cycles. *Geochim Cosmochim Acta* 70: 2238–2252
- Ono S, Shanks WC, Rouxel OJ, Rumble D (2007) S-33 constraints on the seawater sulphate contribution in modern seafloor hydrothermal vent sulfides. *Geochim Cosmochim Acta* 71: 1170–1182
- Onuma N, Clayton RN, Mayeda TK (1970) Oxygen isotope fractionation between minerals and an estimate of the temperature of formation. *Science* 167: 536–538
- Ott U (1993) Interstellar grains in meteorites. *Nature* 364: 25–33
- Owen T, Maillard JP, DeBergh C, Lutz BL (1988) Deuterium on Mars: the abundance of HDO and the value of D/H. *Science* 240: 1767–1770
- Owens NJP (1987) Natural variations in  $^{15}\text{N}$  in the marine environment. *Adv Mar Biol* 24: 390–451
- Pagani M, Arthur MA, Freeman KH (1999a) Miocene evolution of atmospheric carbon dioxide. *Paleoceanography* 14: 273–292
- Pagani M, Freeman KH, Arthur MA (1999b) Late Miocene atmospheric  $\text{CO}_2$  concentrations and the expansion of  $\text{C}_4$  grasses. *Science* 285: 876–879
- Pagani M, Lemarchand D, Spivack A, Gaillardet J (2005) A critical evaluation of the boron isotope- $\text{pH}$  proxy: the accuracy of ancient ocean  $\text{pH}$  estimates. *Geochim Cosmochim Acta* 69: 953–961
- Page FZ, Ushikubo T, Kita NY, Riciputi LR, Valley JW (2007) High precision oxygen isotope analysis of picogram samples reveals 2- $\mu\text{m}$  gradients and slow diffusion in zircon. *Am Miner* 92: 1772–1775
- Palmer MR, Slack JF (1989) Boron isotopic composition of tourmaline from massive sulfide deposits and tourmalinites. *Contr Miner Petrol* 103: 434–451
- Palmer MR, Swihart GH (1996) Boron isotope geochemistry: an overview. *Rev Miner* 33: 709–744
- Palmer MR, Spivack AJ, Edmond JM (1987) Temperature and pH controls over isotopic fractionation during the absorption of boron on marine clays. *Geochim Cosmochim Acta* 51: 2319–2323
- Palmer MR, London D, Morgan GB, Babb HA (1992) Experimental determination of fractionation of  $^{11}\text{B}/^{10}\text{B}$  between tourmaline and aqueous vapor: a temperature- and pressure-dependent isotopic system. *Chem Geol* 101: 123–129
- Palmer MR, Pearson PN, Conbb SJ (1998) Reconstructing past ocean pH-depth profiles. *Science* 282: 1468–1471
- Park R, Epstein S (1960) Carbon isotope fractionation during photosynthesis. *Geochim Cosmochim Acta* 21: 110–126
- Parkinson IJ, Hammond SJ, James RH, Rogers NW (2007) High-temperature lithium isotope fractionation: insights from lithium isotope diffusion in magmatic systems. *Earth Planet Sci Lett* 257: 609–621
- Pawellek F, Veizer J (1994) Carbon cycle in the upper Danube and its tributaries:  $\delta^{13}\text{C}_{\text{DIC}}$  constraints. *Israel J Earth Sci* 43: 187–194
- Paytan A, Kastner M, Campbell D, Thiemens MH (1998) Sulfur isotope composition of Cenozoic seawater sulfate. *Science* 282: 1459–1462
- Paytan A, Luz B, Kolodny Y, Neori A (2002) Biologically mediated oxygen isotope exchange between water and phosphorus. *Global Biogeochem Cycles* 16–13: 1–7
- Paytan A, Kastner M, Campbell D, Thiemens M (2004) Seawater sulfur isotope fluctuations in the Cretaceous. *Science* 304: 1663–1665



- Pearson PN, Palmer MR (1999) Middle Eocene seawater pH and atmospheric carbon dioxide. *Science* 284: 1824–1826
- Pearson PN, Palmer MR (2000) Atmospheric carbon dioxide concentrations over the past 60 million years. *Nature* 406: 695–699
- Pearson NJ, Griffin WL, Alard O, O'Reilly SY (2006) The isotopic composition of magnesium in mantle olivine: records of depletion and metasomatism. *Chem Geol* 226: 115–133
- Peckmann J, Thiel V (2005) Carbon cycling at ancient methane-seeps. *Chem Geol* 205: 443–467
- Pedentchouk N, Freeman KH, Harris NB (2006) Different response of  $\delta D$ -values of n-alkanes, isoprenoids and kerogen during thermal maturation. *Geochim Cosmochim Acta* 70: 2063–2072
- Perry EA, Gieskes JM, Lawrence JR (1976) Mg, Ca and  $^{18}O/^{16}O$  exchange in the sediment-pore water system, Hole 149, DSDP. *Geochim Cosmochim Acta* 40: 413–423
- Peters MT, Wickham SM (1995) On the causes of  $^{18}O$  depletion and  $^{18}O/^{16}O$  homogenization during regional metamorphism, the east Humboldt Range core complex, Nevada. *Contr Miner Petrol* 119: 68–82
- Peters KE, Rohrbach BG, Kaplan IR (1981) Carbon and hydrogen stable isotope variations in kerogen during laboratory-simulated thermal maturation. *Am Assoc Petrol Geol Bull* 65: 501–508
- Peterson BJ, Fry B (1987) Stable isotopes in ecosystem studies. *Ann Rev Ecol Syst* 18: 293–320
- Petit JR, et al. (1999) Climate and atmospheric history of the past 420000 years from the Vostok ice core, Antarctica. *Nature* 399: 429–436
- Phillips FM, Bentley HW (1987) Isotopic fractionation during ion filtration: I. Theory. *Geochim Cosmochim Acta* 51: 683–695
- Pichat S, Douchet C, Albarede F (2003) Zinc isotope variations in deep-sea carbonates from the eastern equatorial Pacific over the last 175 ka. *Earth Planet Sci Lett* 210: 167–178
- Pineau F, Javoy M (1983) Carbon isotopes and concentrations in mid-ocean ridge basalts. *Earth Planet Sci Lett* 62: 239–257
- Pineau F, Javoy M, Bottinga Y (1976)  $^{13}C/^{12}C$  ratios of rocks and inclusions in popping rocks of the Mid-Atlantic Ridge and their bearing on the problem of isotopic composition of deep-seated carbon. *Earth Planet Sci Lett* 29: 413–421
- Poage MA, Chamberlain CP (2001) Empirical relationships between elevation and the stable isotope composition of precipitation and surface waters: considerations for studies of paleoelevation change. *Am J Sci* 301: 1–15
- Poitrasson F, Freydier R (2005) Heavy iron isotope composition of granites determined by high resolution MC-ICP-MS. *Chem Geol* 222: 132–147
- Poitrasson F, Halliday AN, Lee DC, Levasseur S, Teutsch N (2004) Iron isotope differences between Earth, Moon, Mars and Vesta as possible records of contrasted accretion mechanisms. *Earth Planet Sci Lett* 223: 253–266
- Pokrovsky OS, Viers J, Emnova EE, Kompantseva EI, Freydier R (2008) Copper isotope fractionation during its interaction with soil and aquatic microorganisms and metal oxy(hydr)oxides: possible structural control. *Geochim Cosmochim Acta* 72: 1742–1757
- Polyakov VB (1997) Equilibrium fractionation of the iron isotopes: estimation from Mössbauer spectroscopy data. *Geochim Cosmochim Acta* 61: 4213–4217
- Polyakov VB, Kharlashina NN (1994) Effect of pressure on equilibrium isotope fractionation. *Geochim Cosmochim Acta* 58: 4739–4750
- Polyakov VB, Horita J, Cole DR (2006) Pressure effects on the reduced partition function ratio for hydrogen isotopes in water. *Geochim Cosmochim Acta* 70: 1904–1913
- Polyakov VB, Clayton RN, Horita J, Mineev SD (2007) Equilibrium iron isotope fractionation factors of minerals: reevaluation from the data of nuclear inelastic resonant X-ray scattering and Mossbauer spectroscopy. *Geochim Cosmochim Acta* 71: 3833–3846
- Poorter RPE, Varekamp JC, Poreda RJ, Van Bergen MJ, Kreulen R (1991) Chemical and isotopic compositions of volcanic gases from the east Sunda and Banda arcs, Indonesia. *Geochim Cosmochim Acta* 55: 3795–3807
- Popp BN, Takigiku R, Hayes JM, Louda JW, Baker EW (1989) The post Paleozoic chronology and mechanism of  $^{13}C$  depletion in primary organic matter. *Am J Sci* 289: 436–454

- Popp BN, Laws EA, Bidigare RR, Dore JE, Hanson KL, Wakeham SG (1998) Effect of phytoplankton cell geometry on carbon isotope fractionation. *Geochim Cosmochim Acta* 62: 69–77
- Poreda R (1985) Helium-3 and deuterium in back arc basalts: Lau Basin and the Mariana trough. *Earth Planet Sci Lett* 73: 244–254
- Poreda R, Schilling JG, Craig H (1986) Helium and hydrogen isotopes in ocean-ridge basalts north and south of Iceland. *Earth Planet Sci Lett* 78: 1–17
- Poulson RL, Siebert C, McManus J, Berelson WM (2006) Authigenic molybdenum isotope signatures in marine sediments. *Geology* 34: 617–620
- Price FT, Shieh YN (1979) The distribution and isotopic composition of sulfur in coals from the Illinois Basin. *Econ Geol* 74: 1445–1461
- Prokoph A, Shields GA, Veizer J (2008) Compilation and time-series analysis of a marine carbonate  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$ ,  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $\delta^{34}\text{S}$  database through Earth history. *Earth Sci Rev* 87: 113–133
- Prombo CA, Clayton RN (1985) A striking nitrogen isotope anomaly in the Bencubbin and Weatherford meteorites. *Science* 230: 935–937
- Puchelt H, Sabels BR, Hoering TC (1971) Preparation of sulfur hexafluoride for isotope geochemical analysis. *Geochim Cosmochim Acta* 35: 625–628
- Quade J, Cerling TE (1995) Expansion of C4 grasses in the late Miocene of northern Pakistan: evidence from stable isotopes in paleosols. *Palaeogeogr Palaeoclimatol Palaeoecol* 115: 91–116
- Quade J, et al. (1992) A 16-Ma record of paleodiet using carbon and oxygen isotopes in fossil teeth from Pakistan. *Chem Geol* 94: 183–192
- Quast A, Hoefs J, Paul J (2006) Pedogenic carbonates as a proxy for palaeo- $\text{CO}_2$  in the Paleozoic atmosphere. *Palaeogeogr Palaeoclimatol Palaeoecol* 242: 110–125
- Quay PD, Tilbrook B, Wong CS (1992) Oceanic uptake of fossil fuel  $\text{CO}_2$ : carbon-13 evidence. *Science* 256: 74–79
- Quay PD, Emerson S, Wilbur DO, Stump S (1993) The  $\delta^{18}\text{O}$  of dissolved  $\text{O}_2$  in the surface waters of the subarctic Pacific: a tracer of biological productivity. *J Geophys Res* 98: 8447–8458
- Quay PD, Wilbur DO, Richey JE, Devol AH, Benner R, Forsberg BR (1995) The  $^{18}\text{O}/^{16}\text{O}$  of dissolved oxygen in rivers and lakes in the Amazon Basin: determining the ratio of respiration to photosynthesis in freshwaters. *Limnol Oceanogr* 40: 718–729
- Quay PD, Stutsman J, Wibur D, Snover A, Dlugokencky E, Brown T (1999) The isotopic composition of atmospheric methane. *Global Geochemical Cycles* 13: 445–461
- Raab M, Spiro B (1991) Sulfur isotopic variations during seawater evaporation with fractional crystallization. *Chem Geol* 86: 323–333
- Rabinovich AL, Grinenko VA (1979) Sulfate sulfur isotope ratios for USSR river water. *Geochemistry* 16: No 2: 68–79
- Radke J, Bechtel A, Gaupp R, Pittmann W, Schwark L, Sachse D, Gleixner D (2005) Correlation between hydrogen isotope ratios of lipid biomarkers and sediment maturity. *Geochim Cosmochim Acta* 69: 5517–5530
- Rafter TA (1957) Sulphur isotopic variations in nature, P 1: the preparation of sulphur dioxide for mass spectrometer examination. *N Z J Sci Tech B38*: 849
- Rahn T, Wahlen M (1997) Stable isotope enrichment in stratospheric nitrous oxide. *Science* 278: 1776–1778
- Rahn T, Kitchen N, Eiler J (2002a) D/H ratios of atmospheric  $\text{H}_2$  in urban air: results using new methods for analysis of nano-molar  $\text{H}_2$  samples. *Geochim Cosmochim Acta* 66: 2475–2481
- Rahn T, et al. (2002b) The deuterium anomaly in stratospheric molecular hydrogen. *Geochim Cosmochim Acta* 66(spec. suppl): A622
- Railsback LB, Anderson TF, Ackerly SC, Cisne JL (1989) Paleooceanic modeling of temperature-salinity profiles from stable isotope data. *Paleoceanography* 4: 585–591
- Raiswell R, Berner RA (1985) Pyrite formation in euxinic and semi-euxinic sediments. *Am J Sci* 285: 710–724
- Rakestraw NM, Rudd DP, Dole M (1951) Isotopic composition of oxygen in air dissolved in Pacific Ocean water as a function of depth. *J Am Chem Soc* 73: 2976

- Ransom B, Spivack AJ, Kastner M (1995) Stable Cl isotopes in subduction-zone pore waters: implications for fluid-rock reactions and the cycling of chlorine. *Geology* 23: 715–718
- Rau GH, Sweeney RE, Kaplan IR (1982) Plankton  $^{13}\text{C}/^{12}\text{C}$  ratio changes with latitude: differences between northern and southern oceans. *Deep Sea Res* 29: 1035–1039
- Rau GH, Takahashi T, DesMarais DJ (1989) Latitudinal variations in plankton  $^{13}\text{C}$ : implications for  $\text{CO}_2$  and productivity in past ocean. *Nature* 341: 516–518
- Rau GH, Takahashi T, DesMarais DJ, Repeta DJ, Martin JH (1992) The relationship between  $\delta^{13}\text{C}$  of organic matter and  $\Sigma\text{CO}_{2(\text{aq})}$  in ocean surface water: data from a JGOFS site in the northeast Atlantic Ocean and a model. *Geochim Cosmochim Acta* 56: 1413–1419
- Rayleigh JWS (1896) Theoretical considerations respecting the separation of gases by diffusion and similar processes. *Philos Mag* 42: 493
- Redding CE, Schoell M, Monin JC, Durand B (1980) Hydrogen and carbon isotopic composition of coals and kerogen. In: Douglas AG, Maxwell JR (eds.) *Phys Chem Earth* 12: 711–723
- Rees CE (1978) Sulphur isotope measurements using  $\text{SO}_2$  and  $\text{SF}_6$ . *Geochim Cosmochim Acta* 42: 383–389
- Rees CE, Jenkins WJ, Monster J (1978) The sulphur isotopic composition of ocean water sulphate. *Geochim Cosmochim Acta* 42: 377–381
- Rehkämper M, Halliday A (1999) The precise measurement of Tl isotopic compositions by MC-ICPMS: application to the analysis of geological materials and meteorites. *Geochim Cosmochim Acta* 63: 935–944
- Rehkämper M, Frank M, Hein JR, Porcelli D, Halliday A, Ingri J, Libetrau V (2002) Thallium isotope variations in seawater and hydrogenetic, diagenetic and hydrothermal ferromanganese deposits. *Earth Planet Sci Lett* 197: 65–81
- Rehkämper M, Frank M, Hein JR, Halliday A (2004) Cenozoic marine geochemistry of thallium deduced from isotopic studies of ferromanganese crusts and pelagic sediments. *Earth Planet Sci Letters* 219: 77–91
- Reynolds BC, Frank M, Halliday AN (2006) Silicon isotope fractionation during nutrient utilization in the North Pacific. *Earth Planetary Sci Letters* 244: 431–443
- Rice DD, Claypool GE (1981) Generation, accumulation and resource potential of biogenic gas. *Am Assoc Petrol Geol Bull* 65: 5–25
- Richet P, Bottinga Y, Javoy M (1977) A review of H, C, N, O, S, and Cl stable isotope fractionation among gaseous molecules. *Ann Rev Earth Planet Sci* 5: 65–110
- Richter FM (2007) Isotopic fingerprints of mass transport processes. *Geochim Cosmochim Acta* 71: A839
- Richter R, Hoernes S (1988) The application of the increment method in comparison with experimentally derived and calculated O-isotope fractionations. *Chemie der Erde* 48: 1–18
- Richter FM, Liang Y, Davis AM (1999) Isotope fractionation by diffusion in molten oxides. *Geochim Cosmochim Acta* 63: 2853–2861
- Richter FM, Davis AM, DePaolo D, Watson BE (2003) Isotope fractionation by chemical diffusion between molten basalt and rhyolite. *Geochim Cosmochim Acta* 67: 3905–3923
- Riciputi LR, Cole DR, Machel HG (1996) Sulfide formation in reservoir carbonates of the Devonian Nisku Formation, Alberta, Canada: an ion microprobe study. *Geochim Cosmochim Acta* 60: 325–336
- Rietmeijer FJM (1998) Interplanetary dust particles. In: *Planetary materials*. Rev Miner 36: Chapter 2
- Rindsberger MS, Jaffe S, Rahamin S, Gat JR (1990) Patterns of the isotopic composition of precipitation in time and space; data from the Israeli storm water collection program. *Tellus* 42: 263–271
- Ripley EM, Li C (2003) Sulfur isotope exchange and metal enrichment in the formation of magmatic Cu-Ni-(PGE)-deposits. *Econ Geol* 98: 635–641
- Robert F (2001) The origin of water on Earth. *Science* 293: 1056–1058
- Robert F, Chaussidon M (2006) A paleotemperature curve for the Precambrian oceans based on silicon isotopes in cherts. *Nature* 443: 969–972

- Robert F, Epstein S (1982) The concentration and isotopic composition of hydrogen, carbon and nitrogen carbonaceous meteorites. *Geochim Cosmochim Acta* 46: 81–95
- Robert F, Merlivat L, Javoy M (1978) Water and deuterium content in ordinary chondrites. *Meteoritics* 12: 349–354
- Robert F, Gautier D, Dubrulle B (2000) The solar system D/H ratio: observations and theories. *Space Sci Rev* 92: 201–224
- Robinson BW, Kusakabe M (1975) Quantitative preparation of sulphur dioxide for  $^{34}\text{S}/^{32}\text{S}$  analyses from sulphides by combustion with cuprous oxide. *Anal Chem* 47: 1179
- Röckmann T, et al. (1998) Mass independent oxygen isotope fractionation in atmospheric CO as a result of the reaction  $\text{CO} + \text{OH}$ . *Science* 281: 544–546
- Röhl U, Bralower TJ, Norris RD, Wefer G (2000) New chronology for the late Paleocene thermal maximum and its environmental implications. *Geology* 28: 927–930
- Romanek CS, Grossman EL, Morse JW (1992) Carbon isotope fractionation in synthetic aragonite and calcite: effects of temperature and precipitation rate. *Geochim Cosmochim Acta* 56: 419–430
- Romanek CS, et al. (1994) Record of fluid-rock interaction on Mars from the meteorite ALH 84001. *Nature* 372:655–657
- Rooney MA, Claypool GE, Chung HM (1995) Modeling thermogenic gas generation using carbon isotope ratios of natural gas hydrocarbons. *Chem Geol* 126: 219–232
- Rose EF, Chaussidon M, France-Lanord C (2000) Fractionation of boron isotopes during erosion processes: the example of Himalayan rivers. *Geochim Cosmochim Acta* 64: 397–408
- Rosenbaum J, Sheppard SMF (1986) An isotopic study of siderites, dolomites and ankerites at high temperatures. *Geochim Cosmochim Acta* 50: 1147–1150
- Rosman JR, Taylor PD (1998) Isotopic compositions of the elements (technical report): commission on atomic weights and isotopic abundances. *Pure Appl Chem* 70: 217–235
- Rouxel O, Ludden J, Carignan J, Marin L, Fouquet Y (2002) Natural variations in Se isotopic composition determined by hydride generation multiple collector inductively coupled plasma mass spectrometry. *Geochim Cosmochim Acta* 66: 3191–3199
- Rouxel O, Fouquet Y, Ludden JN (2004) Copper isotope systematics of the Lucky Strike, Rainbow and Logatchev seafloor hydrothermal fields on the Mid-Atlantic Ridge. *Econ Geol* 99: 585–600
- Rouxel O, Bekker A, Edwards KJ (2005) Iron isotope constraints on the Archean and Proterozoic ocean redox state. *Science* 307: 1088–1091
- Rouxel O, Galy A, Elderfield H (2006) Germanium isotope variations in igneous rocks and marine sediments. *Geochim Cosmochim Acta* 70: 3387–3400
- Rouxel O, Ono S, Alt J, Rumble D, Ludden J (2008) Sulfur isotope evidence for microbial sulfate reduction in altered oceanic basalts at ODP Site 801. *Earth Planet Sci Lett* 268: 110–123
- Rozanski K, Sonntag C (1982) Vertical distribution of deuterium in atmospheric water vapour. *Tellus* 34: 135–141
- Rozanski K, Araguas-Araguas L, Gonfiantini R (1993) Isotopic patterns in modern global precipitation. In: *Climate change in continental isotopic records*. *Geophys Monogr* 78: 1–36
- Rubinson M, Clayton RN (1969) Carbon-13 fractionation between aragonite and calcite. *Geochim Cosmochim Acta* 33: 997–1002
- Rudnick RL, Ionov DA (2007) Lithium elemental and isotopic disequilibrium in minerals from peridotite xenoliths from far-east Russia: product of recent melt/fluid-rock interaction. *Earth Planet Sci Lett* 256: 278–293
- Rudnick RL, Tomascak PB, Njo HB, Gardner LR (2004) Extreme lithium isotopic fractionation during continental weathering revealed in saprolites from South Carolina. *Chem Geol* 212: 45–57
- Rudnicki MD, Elderfield H, Spiro B (2001) Fractionation of sulfur isotopes during bacterial sulfate reduction in deep ocean sediments at elevated temperatures. *Geochim Cosmochim Acta* 65: 777–789
- Ruiz J, Mathur R, Young S, Brantley S (2002) Controls of copper isotope fractionation. *Geochim Cosmochim Acta Spec Suppl* 66: A654

- Rumble D, Yui TF (1998) The Qinglongshan oxygen and hydrogen isotope anomaly near Donghai in Jiangsu Province, China. *Geochim Cosmochim Acta* 62: 3307–3321
- Russell WA, Papanastassiou DA, Tombrello TA (1978) Ca isotope fractionation on the Earth and other solar system materials. *Geochim Cosmochim Acta* 42: 1075–1090
- Rye RO (1974) A comparison of sphalerite-galena sulfur isotope temperatures with filling-temperatures of fluid inclusions. *Econ Geol* 69: 26–32
- Rye RO (1993) The evolution of magmatic fluids in the epithermal environment: the stable isotope perspective. *Econ Geol* 88: 733–753
- Rye RO (2005) A review of stable isotope geochemistry of sulfate minerals in selected igneous environments and related hydrothermal systems. *Chem Geol* 215: 5–36
- Rye RO, Schuiling RD, Rye DM, Jansen JBH (1976) Carbon, hydrogen and oxygen isotope studies of the regional metamorphic complex at Naxos, Greece. *Geochim Cosmochim Acta* 40: 1031–1049
- Rye RO, Bethke PM, Wasserman MD (1992) The stable isotope geochemistry of acid sulfate. *Econ Geol* 87: 227–262
- Sackett WM (1978) Carbon and hydrogen isotope effects during the thermocatalytic production of hydrocarbons in laboratory simulation experiments. *Geochim Cosmochim Acta* 42: 571–580
- Sackett WM, Thompson RR (1963) Isotopic organic carbon composition of recent continental derived clastic sediments of Eastern Gulf Coast, Gulf of Mexico. *Bull Am Ass Petrol Geol* 47: 525
- Sackett WM, Eadie BJ, Exner ME (1973) Stable isotope composition of organic carbon in recent Antarctic sediments. *Adv Org Geochem* 1973: 661
- Sadofsky SJ, Bebout GE (2000) Ammonium partitioning and nitrogen isotope fractionation among coexisting micas during high-temperature fluid-rock interaction. Examples from the New England Appalachians. *Geochim Cosmochim Acta* 64: 2835–2849
- Saino T, Hattori A (1980)  $^{15}\text{N}$  natural abundance in oceanic suspended particulate organic matter. *Nature* 283: 752–754
- Saino T, Hattori A (1987) Geophysical variation of the water column distribution of suspended particulate organic nitrogen and its  $^{15}\text{N}$  natural abundance in the Pacific and its marginal seas. *Deep Sea Res* 34: 807–827
- Sakai H (1968) Isotopic properties of sulfur compounds in hydrothermal processes. *Geochem J* 2: 29–49
- Sakai H, Casadevall TJ, Moore JG (1982) Chemistry and isotope ratios of sulfur in basalts and volcanic gases at Kilauea volcano, Hawaii. *Geochim Cosmochim Acta* 46: 729–738
- Sakai H, DesMarais DJ, Ueda A, Moore JG (1984) Concentrations and isotope ratios of carbon, nitrogen and sulfur in ocean-floor basalts. *Geochim Cosmochim Acta* 48: 2433–2441
- Sano Y, Marty B (1995) Origin of carbon in fumarolic gas from island arcs. *Chem Geol* 119: 265–274
- Sanyal A, Nugent M, Reeder RJ, Bijma J (2000) Seawater pH control on the boron isotopic composition of calcite: evidence from inorganic calcite precipitation experiments. *Geochim Cosmochim Acta* 64: 1551–1555
- Sarntheim M, et al. (2001) Fundamental modes and abrupt changes in North Atlantic circulation and climate over the last 60 ky - concepts, reconstruction and numerical modeling. In: P Schäfer, W Ritzau, M Schlüter, J Thiede (eds.) *The northern North Atlantic*. Springer Verlag, Heidelberg, p.365–410
- Sasaki A, Arikawa Y, Folinsbee RE (1979) Kiba reagent method of sulfur extraction applied to isotopic work. *Bull Geol Surv Jpn* 30: 241
- Sass E, Kolodny Y (1972) Stable isotopes, chemistry and petrology of carbonate concretions (Mishash formation, Israel). *Chem Geol* 10: 261–286
- Sauer PE, Eglinton TI, Hayes JM, Schimmelmann A, Sessions AL (2001) Compound-specific D/H ratios of lipid biomarkers from sediments as a proxy for environmental and climatic conditions. *Geochim Cosmochim Acta* 65: 213–222

- Savarino J, Lee CCW, Thiemens MH (2000) Laboratory oxygen isotope study of sulfur IV oxidation: origin of the mass-independent oxygen isotope anomaly in atmospheric sulfates and sulfate mineral deposits on Earth. *J Geophys Res (Atm)* 105: 29079–29088
- Savin SM, Epstein S (1970a) The oxygen and hydrogen isotope geochemistry of clay minerals. *Geochim Cosmochim Acta* 34: 25–42
- Savin SM, Epstein S (1970b) The oxygen and hydrogen isotope geochemistry of ocean sediments and shales. *Geochim Cosmochim Acta* 34: 43–63
- Savin SM, Lee M (1988) Isotopic studies of phyllosilicates. *Rev Miner* 19: 189–223
- Schauble EA (2004) Applying stable isotope fractionation theory to new systems. *Rev Miner Geochem* 55: 65–111
- Schauble EA (2007) Role of nuclear volume in driving equilibrium stable isotope fractionation of mercury, thallium and other very heavy elements. *Geochim Cosmochim Acta* 71: 2170–2189
- Schauble EA, Rossman GR, Taylor HP (2001) Theoretical estimates of equilibrium Fe isotope fractionations from vibrational spectroscopy. *Geochim Cosmochim Acta* 65: 2487–2498
- Schauble EA, Rossman GR, Taylor HP (2002) Theoretical estimates of equilibrium chromium isotope fractionations. *Geochim Cosmochim Acta* 66 Spec Suppl A675
- Schauble ES, Rossman GR, Taylor HP (2003) Theoretical estimates of equilibrium chlorine-isotope fractionations. *Geochim Cosmochim Acta* 67: 3267–3281
- Schauble EA, Ghosh P, Eiler JM (2006) Preferential formation of  $^{13}\text{C}$ - $^{18}\text{O}$  bonds in carbonate minerals, estimated using first-principles lattice dynamics. *Geochim Cosmochim Acta* 70: 2510–2519
- Scheele N, Hoefs J (1992) Carbon isotope fractionation between calcite, graphite and  $\text{CO}_2$ . *Contr Miner Petrol* 112: 35–45
- Schiegl WE, Vogel JV (1970) Deuterium content of organic matter. *Earth Planet Sci Lett* 7: 307–313
- Schimmelmann A, Lewan MD, Wintsch RP (1999) D/H ratios of kerogen, bitumen, oil and water in hydrous pyrolysis of source rocks containing kerogen types I, II, IIS and III. *Geochim Cosmochim Acta* 63: 3751–3766
- Schimmelmann A, Sessions AL, Mastalerz M (2006) Hydrogen isotopic (D/H) composition of organic matter during diagenesis and thermal maturation. *Ann. Rev Earth Planet Sci* 34: 501–533
- Schmidt M, Botz R, Stoffers P, Anders T, Bohrmann G (1997) Oxygen isotopes in marine diatoms: a comparative study of analytical techniques and new results on the isotope composition of recent marine diatoms. *Geochim Cosmochim Acta* 61: 2275–2280
- Schmidt M, Botz R, Rickert D, Bohrmann G, Hall SR, Mann S (2001) Oxygen isotopes of marine diatoms and relations to opal-A maturation. *Geochim Cosmochim Acta* 65: 201–211
- Schmitt AD, Stille P, Vennemann T (2003) Variations of the  $^{44}\text{Ca}/^{40}\text{Ca}$  ratio in seawater during the past 24 million years: evidence from  $\delta^{44}\text{Ca}$  and  $\delta^{18}\text{O}$  values of Miocene phosphates. *Geochim Cosmochim Acta* 67: 2607–2614
- Schoell M (1980) The hydrogen and carbon isotopic composition of methane from natural gases of various origins. *Geochim Cosmochim Acta* 44: 649–661
- Schoell M (1983) Genetic characterization of natural gases. *Bull Am Ass Petrol Geol* 67: 2225–2238
- Schoell M (1984) Recent advances in petroleum isotope geochemistry. *Org Geochem* 6: 645–663
- Schoell M (1988) Multiple origins of methane in the Earth. *Chem Geol* 71: 1–10
- Schoell M, McCaffrey MA, Fago FJ, Moldovan JM (1992) Carbon isotope compositions of 28,30-bisnorhopanes and other biological markers in a Monterey crude oil. *Geochim Cosmochim Acta* 56: 1391–1399
- Schoenberg R, Zink S, Staubwasser M, von Blanckenburg F (2008) The stable Cr isotope inventory of solid Earth reservoirs determined by double-spike MC-ICP-MS. *Chem Geol* 249: 294–306
- Schoenheimer R, Rittenberg D (1939) Studies in protein metabolism: I. General considerations in the application of isotopes to the study of protein metabolism. The normal abundance of nitrogen isotopes in amino acids. *J Biol Chem* 127: 285–290



- Schoeninger MJ, DeNiro MJ (1984) Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochim Cosmochim Acta* 48: 625–639
- Scholten SO (1991) The distribution of nitrogen isotopes in sediments. PhD Thesis University of Utrecht
- Schrag DP (1999) Effects of diagenesis on the isotopic record of late Paleogene tropical sea surface temperature. *Chem Geol* 161: 2265–2278
- Schrag DP, Hampt G, Murry DW (1996) Pore fluid constraints on the temperature and oxygen isotopic composition of the Glacial ocean. *Science* 272: 1930–1932
- Schrag DP, Adkins JF, McIntyre K et al (2002) The oxygen isotope composition of sea water during the Glacial ocean. *Quat Sci Rev* 21: 331–342
- Schüßler JA, Schoenberg R, Behrens H, von Blanckenburg F (2007) The experimental calibration of iron isotope fractionation factor between pyrrhotite and peralkaline rhyolitic melt. *Geochim Cosmochim Acta* 71: 417–433
- Schüßler JA, Schoenberg R, Sigmarsson O (2008) Iron and lithium isotope systematics of the Hekla volcano, Iceland: evidence for stable Fe isotope fractionation during magma differentiation. *Chem Geol* (in press)
- Schütze H (1980) Der Isotopenindex - eine Inkrementmethode zur näherungsweisen Berechnung von Isotopenaustauschgleichgewichten zwischen kristallinen Substanzen. *Chemie Erde* 39: 321–334
- Schwalb A, Burns SJ, Kelts K (1999) Holocene environments from stable isotope stratigraphy of ostracods and authigenic carbonate in Chilean Altiplano lakes. *Palaeogeogr Palaeoclimatol Palaeoecol* 148: 153–168
- Schwarz HP, Melbye J, Katzenberg MA, Knyf M (1985) Stable isotopes in human skeletons of southern Ontario: reconstruction of palaeodiet. *J Archaeol Sci* 12: 187–206
- Seal RR (2006) Sulfur isotope geochemistry of sulfide minerals. *Rev Miner Geochem* 61: 633–677
- Seal RR, Alpers CN, Rye RO (2000) Stable isotope systematics of sulfate minerals. *Rev Miner* 40: 541–602
- Seccombe PK, Spry PG, Both RA, Jones MT, Schiller JC (1985) Base metal mineralization in the Kaumantoo Group, South Australia: a regional sulfur isotope study. *Econ Geol* 80: 1824–1841
- Seitz HM, Brey GP, Lahaye Y, Durali S, Weyer S (2004) Lithium isotope signatures of peridotite xenoliths and isotope fractionation at high temperature between olivine and pyroxene. *Chem Geol* 212: 163–177
- Seitz HM, Brey GP, Zipfel J, Ott U, Weyer S, Durali S, Weinbruch S (2007) Lithium isotope composition of ordinary and carbonaceous chondrites and differentiated planetary bodies: bulk solar system and solar reservoirs. *Earth Planet Sci Lett* 260: 582–596
- Sessions AL, Burgoyne TW, Schimmelmann A, Hayes JM (1999) Fractionation of hydrogen isotopes in lipid biosynthesis. *Org Geochem* 30: 1193–1200
- Sessions AL, Sylva SP, Summons RE, Hayes JM (2004) Isotopic exchange of carbon-bound hydrogen over geologic time scales. *Geochim Cosmochim Acta* 68: 1545–1559
- Severinghaus JP, Brook EJ (1999) Abrupt climate change at the end of the last glacial period inferred from trapped air in polar ice. *Science* 286: 930–934
- Severinghaus JP, Bender ML, Keeling RF, Broecker WS (1996) Fractionation of soil gases by diffusion of water vapor, gravitational settling and thermal diffusion. *Geochim Cosmochim Acta* 60: 1005–1018
- Severinghaus JP, Sowers T, Brook EJ, Alley RB, Bender ML (1998) Timing of abrupt climate change at the end of the Younger Dryas interval from thermally fractionated gases in polar ice. *Nature* 391: 141–146
- Severmann S, Johnson CM, Beard BL, German CR, Edmonds HN, Chiba H, Green DRH (2004) The effect of plume processes on the Fe isotope composition of hydrothermally derived Fe in the deep ocean as inferred from the Rainbow vent site, Mid-Atlantic Ridge, 36°14' N. *Earth Planet Sci Lett* 225: 63–76
- Severmann S, Johnson CM, Beard BL, McManus J (2006) The effect of early diagenesis on the Fe isotope composition of porewaters and authigenic minerals in continental margin sediments. *Geochim Cosmochim Acta* 70: 2006–2022

- Shackleton NJ, Kennett JP (1975) Paleotemperature history of the Cenozoic and initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP sites 277, 279 and 281. Initial Rep DSDP 29: 743–755
- Shackleton NJ, Hall MA, Line J, Cane S (1983) Carbon isotope data in core V19–30 confirm reduced carbon dioxide concentration in the ice age atmosphere. *Nature* 306: 319–322
- Shahar A, Young ED, Manning CE (2008) Equilibrium high-temperature Fe isotope fractionation between fayalite and magnetite: an experimental calibration. *Earth Planet Sci Lett* 268: 330–338
- Shanks WC (2001) Stable isotopes in seafloor hydrothermal systems: vent fluids, hydrothermal deposits, hydrothermal alteration, and microbial processes. *Rev Miner Geochem* 43: 469–525
- Sharma T, Clayton RN (1965) Measurement of  $^{18}\text{O}/^{16}\text{O}$  ratios of total oxygen of carbonates. *Geochim Cosmochim Acta* 29: 1347–1353
- Sharp ZD (1990) A laser-based microanalytical method for the in situ determination of oxygen isotope ratios of silicates and oxides. *Geochim Cosmochim Acta* 54: 1353–1357
- Sharp ZD (1995) Oxygen isotope geochemistry of the  $\text{Al}_2\text{SiO}_5$  polymorphs. *Am J Sci* 295: 1058–1076
- Sharp Z (2006) Stable chlorine isotope fractionation. *EOS Trans AGU* 87(52), Fall Meet Suppl V14C–03
- Sharp ZD, Barnes JD, Brearley AJ, Chaussidon M, Fischer TP, Kamenetsky VS (2007) Chlorine isotope homogeneity of the mantle, crust and carbonaceous chondrites. *Nature* 446: 1062–1065
- Shaw AM, Hilton DR, Fischer TP, Walker JA, Alvarado GE (2003) Contrasting He–C relationships in Nicaragua and Costa Rica: insights into C cycling through subduction zones. *Earth Planet Sci Lett* 214: 499–513
- Shelton KL, Rye DM (1982) Sulfur isotopic compositions of ores from Mines Gaspé, Quebec: an example of sulfate–sulfide isotopic disequilibria in ore forming fluids with applications to other porphyry type deposits. *Econ Geol* 77: 1688–1709
- Shemesh A, Kolodny Y, Luz B (1983) Oxygen isotope variations in phosphate of biogenic apatites, II. Phosphorite rocks. *Earth Planet Sci Lett* 64: 405–441
- Shemesh A, Charles CD, Fairbanks RG (1992) Oxygen isotopes in biogenic silica: global changes in ocean temperature and isotopic composition. *Science* 256: 1434–1436
- Shen Y, Buick R (2004) The antiquity of microbial sulfate reduction. *Earth Sci Rev* 64: 243–272
- Sheppard SMF (1986) Characterization and isotopic variations in natural waters. In: stable isotopes in high temperature geological processes. *Rev Miner* 16: 165–183
- Sheppard SMF, Epstein S (1970) D/H and  $\text{O}^{18}/\text{O}^{16}$  ratios of minerals of possible mantle or lower crustal origin. *Earth Planet Sci Lett* 9: 232–239
- Sheppard SMF, Gilg HA (1996) Stable isotope geochemistry of clay minerals. *Clay Miner* 31: 1–24
- Sheppard SMF, Harris C (1985) Hydrogen and oxygen isotope geochemistry of Ascension Island lavas and granites: variation with crystal fractionation and interaction with sea water. *Contrib Miner Petrol* 91: 74–81
- Sheppard SMF, Schwarcz HP (1970) Fractionation of carbon and oxygen isotopes and magnesium between coexisting metamorphic calcite and dolomite. *Contr Miner Petrol* 26: 161–198
- Sheppard SMF, Nielsen RL, Taylor HP (1971) Hydrogen and oxygen isotope ratios in minerals from Porphyry Copper Deposits. *Econ Geol* 66: 515–542
- Sherwood Lollar B, Frape SK, Weisz SM, Fritz P, Macko SA, Welhan JA (1993) Abiogenic methanogenesis in crystalline rocks. *Geochim Cosmochim Acta* 57: 5087–5097
- Sherwood Lollar B, Westgate TD, Ward JA, Slater GF, Lacrampe-Couloume G (2002) Abiogenic formation of alkanes in the Earth's crust as a minor source for global hydrocarbons reservoirs. *Nature* 416: 522–524
- Sherwood Lollar B, et al. (2006) Unravelling abiogenic and biogenic sources of methane in the earth's deep subsurface. *Chem Geol* 226: 328–339
- Shieh YN, Schwarcz HP (1974) Oxygen isotope studies of granite and migmatite, Grenville province of Ontario, Canada. *Geochim Cosmochim Acta* 38: 21–45

- Shields G, Veizer J (2002) Precambrian marine carbonate isotope database: version 1.1. *Geochem Geophys Geosyst* 300: doi: 10.1029/2001GC000266
- Shields WR, Goldich SS, Garner EI, Murphy TJ (1965) Natural variations in the abundance ratio and the atomic weight of copper. *J Geophys Res* 70: 479–491
- Shmulovich KI, Landwehr D, Simon K, Heinrich W (1999) Stable isotope fractionation between liquid and vapour in water-salt systems up to 600°C. *Chem Geol* 157: 343–354
- Siebert C, Nägler TF, von Blanckenburg F, Kramers JD (2003) Molybdenum isotope records as potential proxy for paleoceanography. *Earth Planet Sci Lett* 211: 159–171
- Siebert C, Kramers JD, Meisel T, Morel P, Nägler TF (2005) PGE, Re-Os and Mo isotope systematics in Archean and early Proterozoic sedimentary systems as proxies for redox conditions of the early Earth. *Geochim Cosmochim Acta* 69: 1787–1801
- Siebert C, Ross A, McManus J (2006a) Germanium isotope measurements of high-temperature geothermal fluids using double-spike hydride generation MC-ICP-MS. *Geochim Cosmochim Acta* 70: 3986–3995
- Siebert C, McManus J, Bice A, Poulson R, Berelson WM (2006b) Molybdenum isotope signatures in continental margin sediments. *Earth Planet Sci Lett* 241: 723–733
- Sime NG, De la Rocha C, Galy A (2005) Negligible temperature dependence of calcium isotope fractionation in 12 species of planktonic foraminifera. *Earth Planet Sci Lett* 232: 51–66
- Simon K (2001) Does  $\delta D$  from fluid inclusions in quartz reflect the original hydrothermal fluid? *Chem Geol* 177: 483–495
- Skauli H, Boyce AJ, Fallick AE (1992) A sulphur isotope study of the Bleikvassli Zn-Pb-Cu deposit, Nordland, northern Norway. *Miner Deposita* 27: 284–292
- Skirrow R, Coleman ML (1982) Origin of sulfur and geothermometry of hydrothermal sulfides from the Galapagos Rift, 86°W. *Nature* 249: 142–144
- Skulan JL, DePaolo DJ, Owens TL (1997) Biological control of calcium isotopic abundances in the global calcium cycle. *Geochim Cosmochim Acta* 61: 2505–2510
- Slack JF, Palmer MR, Stevens BPJ, Barnes RG (1993) Origin and significance of tourmaline-rich rocks in the Broken Hill district, Australia. *Econ Geol* 88: 505–541
- Smith JW, Batts BD (1974) The distribution and isotopic composition of sulfur in coal. *Geochim Cosmochim Acta* 38: 121–123
- Smith MP, Yardley BWD (1996) The boron isotopic composition of tourmaline as a guide to fluid processes in the southwestern England orefield: an ion microprobe study. *Geochim Cosmochim Acta* 60: 1415–1427
- Smith JW, Gould KW, Rigby D (1982) The stable isotope geochemistry of Australian coals. *Org Geochem* 3: 111–131
- Smith CN, Kesler SE, Klaue B, Blum J (2005) Mercury isotope fractionation in fossil hydrothermal systems. *Geology* 33: 825–828
- Smith CN, Kesler SE, Blum JD, Rytuba JR (2008) Isotope geochemistry of mercury in source rocks, mineral deposits and spring deposits of the California Coast Ranges, USA. *Earth Planet Sci Lett* 269: 398–406
- Snyder G, Poreda R, Hunt A, Fehn U (2001) Regional variations in volatile composition: isotopic evidence for carbonate recycling in the Central American volcanic arc. *Geochem Geophys Geosystems* 2: U1–U32
- Sofer Z (1984) Stable carbon isotope compositions of crude oils: application to source depositional environments and petroleum alteration. *Am Assoc Petrol Geol Bull* 68: 31–49
- Sofer Z, Gat JR (1972) Activities and concentrations of oxygen-18 in concentrated aqueous salt solutions: analytical and geophysical implications. *Earth Planet Sci Lett* 15: 232–238
- Sonnerup RE, Quay PD, McNichol AP, Bullister JL, Westby TA, Anderson HL (1999) Reconstructing the oceanic  $^{13}C$  Suess effect. *Global Biogeochem Cycles* 13: 857–872
- Sowers T (2001) The  $N_2O$  record spanning the penultimate deglaciation from the Vostok ice core. *J Geophys Res* 106: 31903–31914
- Sowers T, Bender M, Raynaud D, Korotkevich YS, Orchardo J (1991) The  $\delta^{18}O$  of atmospheric  $O_2$  from air inclusions in the Vostok ice core: timing of  $CO_2$  and ice volume changes during the Penultimate deglaciation. *Paleoceanography* 6: 679–696

- Sowers T, Bender M, Raynaud D, Korotkevich YS (1992)  $\delta^{15}\text{N}$  of  $\text{N}_2$  in air trapped in polar ice: a tracer of gas transport in the firn and a possible constraint on ice age-gas age differences. *J Geophys Res* 97: 15683–15697
- Sowers T, et al. (1993) A 135000 year Vostock-SPECMAP common temporal framework. *Paleoceanography* 8: 737–766
- Spero HJ, Bijma J, Lea DW, Bemis BE (1997) Effect of seawater carbonate concentration on foraminiferal carbon and oxygen isotopes. *Nature* 390: 497–500
- Spivack AJ, Edmond JM (1986) Determination of boron isotope ratios by thermal ionization mass spectrometry of the dicesium metaborate cation. *Anal Chem* 58: 31–35
- Spivack AJ, Edmond JM (1987) Boron isotope exchange between seawater and the oceanic crust. *Geochim Cosmochim Acta* 51: 1033–1043
- Spivack AJ, Kastner M, Ransom B (2002) Elemental and isotopic chloride geochemistry in the Nankai trough. *Geophysical Res Lett* 29: 1661, doi:10.1029/2001GL014122
- Stahl W (1977) Carbon and nitrogen isotopes in hydrocarbon research and exploration. *Chem Geol* 20: 121–149
- Stein LY, Yung YL (2003) Production, isotopic composition, and atmospheric fate of biologically produced nitrous oxide. *Ann Rev Earth Planet Sci* 31: 329–356
- Stern LA, Chamberlain CP, Reynolds RC, Johnson GD (1997) Oxygen isotope evidence of climate change from pedogenic clay minerals in the Himalayan molasse. *Geochim Cosmochim Acta* 61: 731–744
- Stern MJ, Spindel W, Monse EU (1968) Temperature dependence of isotope effects. *J Chem Phys* 48: 2908
- Steuber T, Buhl D (2006) Calcium-isotope fractionation in selected modern and ancient marine carbonates. *Geochim Cosmochim Acta* 70: 5507–5521
- Stevens CM (1988) Atmospheric methane. *Chem Geol* 71: 11–21
- Stevens CM, Krout L, Walling D, Venters A, Engelkemeier A, Ross LE (1972) The isotopic composition of atmospheric carbon monoxide. *Earth Planet Sci Lett* 16: 147–165
- Stewart MK (1974) Hydrogen and oxygen isotope fractionation during crystallization of mirabilite and ice. *Geochim Cosmochim Acta* 38: 167–172
- Strauß H (1997) The isotopic composition of sedimentary sulfur through time. *Palaeogeogr Palaeoclimatol Palaeoecol* 132: 97–118
- Strauß H (1999) Geological evolution from isotope proxy signals - sulfur. *Chem Geol* 161: 89–101
- Strauß H, Peters-Kottig W (2003) The Phanerozoic carbon cycle revisited: the carbon isotope composition of terrestrial organic matter. *G<sup>3</sup> Geochem Geophys Geosys* 4: 1083 doi: 10.1029/2003GC000555
- Stueber AM, Walter LM (1991) Origin and chemical evolution of formation waters from Silurian - Devonian strata in the Illinois basin. *Geochim Cosmochim Acta* 55: 309–325
- Sturchio NC, Hatzinger PB, Atkins MD, Suh C, Heraty LJ (2003) Chlorine isotope fractionation during microbial reduction of perchlorate. *Environ Sci Technol* 37: 3859–3863
- Styrt MM, Brackmann AJ, Holland HD, Clark BC, Pisutha-Arnold U, Eldridge CS, Ohmoto H (1981) The mineralogy and the isotopic composition of sulfur in hydrothermal sulfide/sulfate deposits on the East Pacific Rise, 21°N latitude. *Earth Planet Sci Lett* 53: 382–390
- Summons RE, Jahnke LL, Roksandic Z (1994) Carbon isotopic fractionation in lipids from methanotrophic bacteria: relevance for interpretation of the geochemical record of biomarkers. *Geochim Cosmochim Acta* 58: 2853–2863
- Sugawara S, Nakazawa T, Shirakawa Y, Kawamura K, Aoki S, Machida T, Honda H (1998) Vertical profile of the carbon isotope ratio of stratospheric methane over Japan. *Geophysic Res Lett* 24: 2989–2992
- Suzuoki T, Epstein S (1976) Hydrogen isotope fractionation between OH-bearing minerals and water. *Geochim Cosmochim Acta* 40: 1229–1240
- Swart PK, Burns SJ, Leder JJ (1991) Fractionation of the stable isotopes of oxygen and carbon in carbon dioxide during the reaction of calcite with phosphoric acid as a function of temperature and technique. *Chem Geol* 86: 89–96

- Sweeney RE, Kaplan IR (1980) Natural abundance of  $^{15}\text{N}$  as a source indicator for near-shore marine sedimentary and dissolved nitrogen. *Mar Chem* 9: 81–94
- Sweeney RE, Liu KK, Kaplan IR (1978) Oceanic nitrogen isotopes and their use in determining the source of sedimentary nitrogen. In: Robinson BW (ed.) *DSIR Bull* 220: 9–26
- Swihart GH (1996) Instrumental techniques for boron isotope analysis. *Rev Miner* 33: 845–862
- Swihart GH, Moore PB (1989) A reconnaissance of the boron isotopic composition of tourmaline. *Geochim Cosmochim Acta* 53: 911–916
- Swihart GH, Moore PB, Callis EL (1986) Boron isotopic composition of marine and non-marine evaporite borates. *Geochim Cosmochim Acta* 50: 1297–1301
- Talbot MR (1990) A review of the palaeohydrological interpretation of carbon and oxygen isotopic ratios in primary lacustrine carbonates. *Chem Geol* 80: 261–279
- Tanaka R, Nakamura E (2005) Boron isotopic constraints on the source of Hawaiian shield lavas. *Geochim Cosmochim Acta* 69: 3385–3399
- Tang Y, Perry JK, Jenden PD, Schoell M (2000) Mathematical modeling of stable carbon isotope ratios in natural gases. *Geochim Cosmochim Acta* 64: 2673–2687
- Tang Y, Huang Y, Ellis GS, Wang Y, Kralert PG, Gillaizeau B, Ma Q, Hwang R (2005) A kinetic model for thermally induced hydrogen and carbon isotope fractionation of individual n-alkanes in crude oil. *Geochim Cosmochim Acta* 69: 4505–4520
- Taran YA, Klier GA, Sevastianov VS (2007) Carbon isotope effect in the open system Fischer Trosch synthesis. *Geochim Cosmochim Acta* 71: 4474–4487
- Tarutani T, Clayton RN, Mayeda TK (1969) The effect of polymorphism and magnesium substitution on oxygen isotope fractionation between calcium carbonate and water. *Geochim Cosmochim Acta* 33: 987–996
- Taube H (1954) Use of oxygen isotope effects in the study of hydration ions. *J Phys Chem* 58: 523
- Taylor HP (1968) The oxygen isotope geochemistry of igneous rocks. *Contr Miner Petrol* 19: 1–71
- Taylor HP (1974) The application of oxygen and hydrogen isotope studies to problems of hydrothermal alteration and ore deposition. *Econ Geol* 69: 843–883
- Taylor HP (1977) Water/rock interactions and the origin of  $\text{H}_2\text{O}$  in granite batholiths. *J Geol Soc* 133: 509
- Taylor HP (1978) Oxygen and hydrogen isotope studies of plutonic granitic rocks. *Earth Planet Sci Lett* 38: 177–210
- Taylor HP (1980) The effects of assimilation of country rocks by magmas on  $^{18}\text{O}/^{16}\text{O}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  systematics in igneous rocks. *Earth Planet Sci Lett* 47: 243–254
- Taylor BE (1986) Magmatic volatiles: isotopic variation of C, H and S. *Rev Miner* 16: 185–225
- Taylor BE (1987) Stable isotope geochemistry of ore-forming fluids. In: stable isotope geochemistry of low-temperature fluids. *Short Course Min Ass Canada Vol* 13: 337–445
- Taylor HP (1986) Igneous rocks: II. Isotopic case studies of circumpacific magmatism. In: stable isotopes in high temperature geological processes. *Rev Miner* 16: 273–317
- Taylor HP (1987) Comparison of hydrothermal systems in layered gabbros and granites, and the origin of low- $\delta^{18}\text{O}$  magmas. In: *Magmatic processes: physicochemical principles*. *Geochem Soc Spec Publ* 1: 337–357
- Taylor HP (1988) Oxygen, hydrogen and strontium isotope constraints on the origin of granites. *Trans R Soc Edinburgh: Earth Sci* 79: 317–338
- Taylor HP (1997) Oxygen and hydrogen isotope relationships in hydrothermal mineral deposits. In: Barnes HL (ed) *Geochemistry of hydrothermal ore deposits*, 3rd ed. New York, Wiley-Interscience p. 229–302
- Taylor BE, Bucher-Nurminen K (1986) Oxygen and carbon isotope and cation geochemistry of metasomatic carbonates and fluids - Bergell aureole, Northern Italy. *Geochim Cosmochim Acta* 50: 1267–1279
- Taylor HP, Epstein S (1962) Relation between  $^{18}\text{O}/^{16}\text{O}$  ratios in coexisting minerals of igneous and metamorphic rocks. I Principles and experimental results. *Geol Soc Am Bull* 73: 461–480
- Taylor HP, Forester RW (1979) An oxygen and hydrogen isotope study of the Skaergaard intrusion and its country rocks: a description of a 55 M.Y. old fossil hydrothermal system. *J Petrol* 20: 355–419

- Taylor BE, O'Neil JR (1977) Stable isotope studies of metasomatic Ca-Fe-Al-Si skarns and associated metamorphic and igneous rocks, Osgood Mountains, Nevada. *Contr Miner Petrol* 63: 1–49
- Taylor HP, Sheppard SMF (1986) Igneous rocks: I. Processes of isotopic fractionation and isotope systematics. In: *Stable isotopes in high temperature geological processes*. *Rev Miner* 16: 227–271
- Taylor TI, Urey HC (1938) Fractionation of the lithium and potassium isotopes by chemical exchange with zeolites. *J Chem Phys* 6: 429–438
- Taylor BE, Wheeler MC (1994) Sulfur- and oxygen isotope geochemistry of acid mine drainage in the Western United States. In: *Environmental geochemistry of sulphide oxidation*. *Am Chem Soc. Symp ser* 550: 481–514, American Chemical Society Washington, DC
- Taylor BE, Eichelberger JC, Westrich HR (1983) Hydrogen isotopic evidence of rhyolitic magma degassing during shallow intrusion and eruption. *Nature* 306: 541–545
- Taylor HP, Turi B, Cundari A (1984)  $^{18}\text{O}/^{16}\text{O}$  and chemical relationships in K-rich volcanic rocks from Australia, East Africa, Antarctica and San Venzano Cupaello, Italy. *Earth Planet Sci Lett* 69: 263–276
- Teece MA, Fogel ML (2007) Stable carbon isotope biogeochemistry of monosaccharides in aquatic organisms and terrestrial plants. *Org Geochem* 38: 458–473
- Telmer KH, Veizer J (1999) Carbon fluxes,  $\text{pCO}_2$  and substrate weathering in a large northern river basin, Canada: carbon isotope perspective. *Chem Geol* 159: 61–86
- Teng FZ, et al. (2004) Lithium isotope composition and concentration of the upper continental crust. *Geochim Cosmochim Acta* 68: 4167–4178
- Teng FZ, McDonough WF, Rudnick RL, Walker RJ (2006) Diffusion-driven extreme lithium isotopic fractionation in country rocks of the Tin Mountain pegmatite. *Earth Planet Sci Lett* 243: 701–710
- Teng FZ, McDonough WF, Rudnick RL, Wing BA (2007) Limited lithium isotopic fractionation during progressive metamorphic dehydration in metapelites: a case study from the Onawa contact aureole, Maine. *Chem Geol* 239: 1–12
- Thiel V, Peckmann J, Seifert R, Wehrung P, Reitner J, Michaelis W (1999) Highly isotopically depleted isoprenoids: molecular markers for ancient methane venting. *Geochim Cosmochim Acta* 63: 3959–3966
- Thiemen MH (1988) Heterogeneity in the nebula: Evidence from stable isotopes. In: JF Kerridge, MS Matthews (eds.) *Meteorites and the early solar system*. University of Arizona Press, Arizona, p. 899–923
- Thiemen MH (1999) Mass-independent isotope effects in planetary atmospheres and the early solar system. *Science* 283: 341–345
- Thiemen MH (2006) History and applications of mass-independent isotope effects. *Annu Rev Earth Planet Sci* 34: 217–262
- Thiemen MH, Heidenreich JE (1983) The mass independent fractionation of oxygen - A novel isotope effect and its cosmochemical implications. *Science* 219: 1073–1075
- Thiemen MH, Jackson T, Zipf EC, Erdman PW, van Egmond C (1995) Carbon dioxide and oxygen isotope anomalies in the mesosphere and stratosphere. *Science* 270: 969–972
- Thode HG, Monster J (1964) The sulfur isotope abundances in evaporites and in ancient oceans. In: Vinogradov AP (ed) *Proc Geochem Conf Commemorating the Centenary of V I Vernadskii's Birth*, vol 2, 630 p
- Thode HG, Macnamara J, Collins CB (1949) Natural variations in the isotopic content of sulphur and their significance. *Can J Res* 27: 361
- Thompson P, Schwarcz HP, Ford DE (1974) Continental Pleistocene climatic variations from speleothem age and isotopic data. *Science* 184: 893–895
- Thompson LG, Mosley-Thompson E, Henderson KA (2000) Ice-core palaeoclimate records in tropical South America since the last glacial maximum. *J Quaternary Sci* 15: 377–394
- Thompson LG, et al. (2006) Abrupt tropical climate change: past and present. *Proc Nat Acad Sci* 103: 10536–10543



- Tiedemann R, Sarntheim M, Shackleton NJ (1994) Astronomic timescale for the Pliocene Atlantic  $\delta^{18}\text{O}$  and dust flux records of Ocean Drilling Program site 659: *Paleoceanography* 9: 619–638
- Tipper ET, Galy A, Gaillardet J, Bickle MJ, Elderfield H, Carder EA (2006) The magnesium isotope budget of the modern ocean: constraints from riverine magnesium isotope ratios. *Earth Planet Sci Lett* (in press)
- Todd CS, Evans BW (1993) Limited fluid-rock interaction at marble-gneiss contacts during Cretaceous granulite-facies metamorphism, Seward Peninsula, Alaska. *Contr Miner Petrol* 114: 27–41
- Tomaschak PB, Tera F, Helz RT, Walker RJ (1999) The absence of lithium isotope fractionation during basalt differentiation: new measurements by multicollector sector ICP-MS. *Geochim Cosmochim Acta* 63: 907–910
- Tomaschak PB, Ryan JG, Defant MJ (2000) Lithium isotope evidence for light element decoupling in the Panama subarc mantle. *Geology* 28: 507–510
- Tomaschak PB, Widom E, Benton LD, Goldstein SL, Ryan JG (2002) The control of lithium budgets in island arcs. *Earth Planet Sci Lett* 196: 227–238
- Tomaszak PB (2004). Lithium isotopes in earth and planetary sciences. *Rev Miner Geochem*
- Trofimov A (1949) Isotopic constitution of sulfur in meteorites and in terrestrial objects. *Dokl Akad Nauk SSSR* 66: 181
- Trudinger PA, Chambers LA, Smith JW (1985) Low temperature sulphate reduction: biological versus abiological. *Can J Earth Sci* 22: 1910–1918
- Trudinger CM, Enting IG, Francey RJ, Etheridge DM, Rayner PJ (1999) Long-term variability in the global carbon cycle inferred from a high-precision  $\text{CO}_2$  and  $\delta^{13}\text{C}$  ice-core record. *Tellus* 51: 233–248
- Truesdell AH (1974) Oxygen isotope activities and concentrations in aqueous salt solution at elevated temperatures: consequences for isotope geochemistry. *Earth Planet Sci Lett* 23: 387–396
- Truesdell AH, Hulston JR (1980) Isotopic evidence on environments of geothermal systems. In: Fritz P, Fontes J (eds) *Handbook of environmental isotope geochemistry*, vol I. Elsevier, New York, Amsterdam, pp 179–226
- Tucker ME, Wright PV (1990) *Carbonate sedimentology*. Blackwell, Oxford, p. 365–400
- Turchyn AV, Schrag DP (2004) Oxygen isotope constraints on the sulfur cycle over the past 10 million years. *Science* 303: 2004–2007
- Turner JV (1982) Kinetic fractionation of carbon-13 during calcium carbonate precipitation. *Geochim Cosmochim Acta* 46: 1183–1192
- Ueda A, Sakai S (1984) Sulfur isotope study of Quaternary volcanic rocks from the Japanese Island Arc. *Geochim Cosmochim Acta* 48: 1837–1848
- Urey HC (1947) The thermodynamic properties of isotopic substances. *J Chem Soc* 1947: 562
- Urey HC, Brickwedde FG, Murphy GM (1932) A hydrogen isotope of mass 2 and its concentration. *Phys Rev* 40: 1
- Usdowski E, Hoefs J (1993) Oxygen isotope exchange between carbonic acid, bicarbonate, carbonate, and water: a re-examination of the data of McCrea and an expression for the overall partitioning of oxygen isotopes between the carbonate species and water. *Geochim Cosmochim Acta* 57: 3815–3818
- Valley JW (1986) Stable isotope geochemistry of metamorphic rocks. *Rev Miner* 16: 445–489
- Valley JW (2001) Stable isotope thermometry at high temperatures. *Rev Miner Geochem* 43: 365–413
- Valley JW (2003) Oxygen isotopes in zircon. *Rev Miner Geochem* 53: 343–385
- Valley JW, Graham C (1993) Cryptic grain-scale heterogeneity of oxygen isotope ratios in metamorphic magnetite. *Science* 259: 1729–1733
- Valley JW, O'Neil JR (1981)  $^{13}\text{C}/^{12}\text{C}$  exchange between calcite and graphite: a possible thermometer in Greville marbles. *Geochim Cosmochim Acta* 45: 411–419
- Valley JW, Bohlen SR, Essene EJ, Lamb W (1990) Metamorphism in the Adirondacks. II. *J Petrol* 31: 555–596

- Valley JW, Eiler JM, Graham CM, Gibson EK, Romanek CS, Stolper EM (1997) Low temperature carbonate concretions in the martian meteorite ALH 84001: evidence from stable isotopes and mineralogy. *Science* 275: 1633–1637
- Valley J, Graham CM, Harte B, Eiler JM, Kinney PD (1998) Ion microprobe analysis of oxygen, carbon and hydrogen isotope ratios. In: Applications of microanalytical techniques to understanding mineralizing processes. *Rev Econ Geol* 7: 73–98
- Valley JW, et al. (2005) 4.4 billion years of crustal maturation: oxygen isotope ratios in magmatic zircon. *Contr Miner Petrol* 150: 561–580
- Van Warmerdam EM, Frapce SK, Aravena R, Drimmie RJ, Flatt H, Cherry JA (1995) Stable chlorine and carbon isotope measurements of selected chlorinated organic solvents. *Appl Geochem* 10: 547–552
- Vasconcelos C, Mackenzie JA, Warthmann R, Bernasconi S (2005) Calibration of the  $\delta^{18}\text{O}$  paleothermometer for dolomite precipitated in microbial cultures and natural environments. *Geology* 33: 317–320
- Vazquez R, Vennemann TW, Kesler SE, Russell N (1998) Carbon and oxygen isotope halos in the host limestone, El Mochito Zn, Pb (Ag) skarn massive sulfide/oxide deposit, Honduras. *Econ Geol* 93: 15–31
- Veizer J, Hoefs J (1976) The nature of  $^{18}\text{O}/^{16}\text{O}$  and  $^{13}\text{C}/^{12}\text{C}$  secular trends in sedimentary carbonate rocks. *Geochim Cosmochim Acta* 40: 1387–1395
- Veizer J, et al. (1997) Oxygen isotope evolution of Phanerozoic seawater. *Palaeogeogr Palaeoclimatol Palaeoecol* 132: 159–172
- Veizer J, et al. (1999)  $^{87}\text{Sr}/^{86}\text{Sr}$ ,  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  evolution of Phanerozoic seawater. *Chem Geol* 161: 37–57
- Vengosh A, Chivas AR, McCulloch M, Starinsky A, Kolodny Y (1991a) Boron isotope geochemistry of Australian salt lakes. *Geochim Cosmochim Acta* 55: 2591–2606
- Vengosh A, Starinsky A, Kolodny Y, Chivas AR (1991b) Boron isotope geochemistry as a tracer for the evolution of brines and associated hot springs from the Dead Sea, Israel. *Geochim Cosmochim Acta* 55: 1689–1695
- Vennemann T, O'Neil JR (1996) Hydrogen isotope exchange reactions between hydrous minerals and hydrogen: I. A new approach for the determination of hydrogen isotope fractionation at moderate temperatures. *Geochim Cosmochim Acta* 60: 2437–2451
- Vennemann TW, Smith HS (1992) Stable isotope profile across the orthoamphibole isograd in the Southern Marginal Zone of the Limpopo Belt, S Africa. *Precambrian Res* 55: 365–397
- Vennemann TW, Kesler SE, O'Neil JR (1992) Stable isotope composition of quartz pebbles and their fluid inclusions as tracers of sediment provenance: implications for gold- and uranium-bearing quartz pebble conglomerates. *Geology* 20: 837–840
- Vennemann TW, Kesler SE, Frederickson GC, Minter WEL, Heine RR (1996) Oxygen isotope sedimentology of gold and uranium-bearing Witwatersrand and Huronian Supergroup quartz pebble conglomerates. *Econ Geol* 91: 322–342
- Vennemann TW, Fricke HC, Blake RE, O'Neil JR, Colman A (2002) Oxygen isotope analysis of phosphates: a comparison of techniques for analysis of  $\text{Ag}_3\text{PO}_4$ . *Chem Geol* 185: 321–336
- Vogel JC, Grootes PM, Mook WG (1970) Isotopic fractionation between gaseous and dissolved carbon dioxide. *Z Physik* 230: 225–238
- von Grafenstein U, Erlenkeuser H, Trumborn P (1999) Oxygen and carbon isotopes in fresh-water ostracod valves: assessing vital offsets and autoecological effects of interest for paleoclimate studies. *Palaeogeogr Palaeoclimatol Palaeoecol* 148: 133–152
- Wachter EA, Hayes JM (1985) Exchange of oxygen isotopes in carbon dioxide-phosphoric acid systems. *Chem Geol* 52: 365–374
- Wada E, Hattori A (1976) Natural abundance of  $^{15}\text{N}$  in particulate organic matter in North Pacific Ocean. *Geochim Cosmochim Acta* 40: 249–251
- Wallmann K (2001) The geological water cycle and the evolution of marine  $\delta^{18}\text{O}$  values. *Geochim. Cosmochim Acta* 65: 2469–2485
- Wang Z, Schauble EA, Eiler JM (2004) Equilibrium thermodynamics of multiply substituted isotopologues of molecular gas. *Geochim Cosmochim Acta* 68: 4779–4797

- Warren CG (1972) Sulfur isotopes as a clue to the genetic geochemistry of a roll-type uranium deposit. *Econ Geol* 67: 759–767
- Watson LL, Hutcheon ID, Epstein S, Stolper EM (1994) Water on Mars: clues from deuterium/hydrogen and water contents of hydrous phases in SNC meteorites. *Science* 265: 86–90
- Weber JN, Raup DM (1966a) Fractionation of the stable isotopes of carbon and oxygen in marine calcareous organisms—the Echinoidea. I. Variation of  $^{13}\text{C}$  and  $^{18}\text{O}$  content within individuals. *Geochim Cosmochim Acta* 30: 681–703
- Weber JN, Raup DM (1966b) Fractionation of the stable isotopes of carbon and oxygen in marine calcareous organisms—the Echinoidea. II. Environmental and genetic factors. *Geochim Cosmochim Acta* 30: 705–736
- Wefer G, Berger WH (1991) Isotope paleontology: growth and composition of extant calcareous species. *Mar Geol* 100: 207–248
- Wei CS, Zhao ZF, Spicuzza MJ (2008) Zircon oxygen isotopic constraint on the sources of late Mesozoic A-type granites in eastern China. *Chem Geol* 250: 1–15
- Welhan JA (1987) Stable isotope hydrology. In: Short course in stable isotope geochemistry of low-temperature fluids. *Miner Ass Canada Vol 13*: 129–161
- Welhan JA (1988) Origins of methane in hydrothermal systems. *Chem Geol* 71: 183–198
- Wenzel B, Lecuyer C, Joachimski MM (2000) Comparing oxygen isotope records of Silurian calcite and phosphate -  $\delta^{18}\text{O}$  composition of brachiopods and conodonts. *Geochim Cosmochim Acta* 69: 1859–1872
- Westerhausen L, Poynter J, Eglinton G, Erlenkeuser H, Sarntheim M (1993) Marine and terrigenous origin of organic matter in modern sediments of the equatorial East Atlantic: the  $\delta^{13}\text{C}$  and molecular record. *Deep Sea Res* 40: 1087–1121
- Weyer S, Anbar AD, Brey GP, Münker C, Mezger K (2005) Iron isotope fractionation during planetary differentiation. *Earth Planet Sci Lett* 240: 251–264
- White JWC (1989) Stable hydrogen isotope ratios in plants: a review of current theory and some potential applications. In: *Stable isotopes in ecological research*. Ecological Studies 68. Springer Verlag, New York, p.142–162
- White JWC, Lawrence JR, Broecker WS (1994) Modeling and interpreting D/H ratios in tree rings: a test case of white pine in the northeastern United States. *Geochim Cosmochim Acta* 58: 851–862
- Whiticar MJ (1999) Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane. *Chem Geol* 161: 291–314
- Whiticar MJ, Faber E, Schoell M (1986) Biogenic methane formation in marine and freshwater environments:  $\text{CO}_2$  reduction vs. acetate fermentation—Isotopic evidence. *Geochim Cosmochim Acta* 50: 693–709
- Whittaker SG, Kyser TK (1990) Effects of sources and diagenesis on the isotopic and chemical composition of carbon and sulfur in Cretaceous shales. *Geochim Cosmochim Acta* 54: 2799–2810
- Wickham SM, Taylor HR (1985) Stable isotope evidence for large-scale seawater infiltration in a regional metamorphic terrane; the Trois Seigneurs Massif, Pyrenees, France. *Contrib Miner Petrol* 91: 122–137
- Wickman FE (1952) Variation in the relative abundance of carbon isotopes in plants. *Geochim Cosmochim Acta* 2: 243–254
- Wiechert U, Hoefs J (1995) An excimer laser-based microanalytical preparation technique for in-situ oxygen isotope analysis of silicate and oxide minerals. *Geochim Cosmochim Acta* 59: 4093–4101
- Wiechert U, Halliday AN, Lee DC, Snyder GA, Taylor LA, Rumble D (2001) Oxygen isotopes and the moon forming giant impact. *Science* 294: 345–348
- Wiechert U, Fiebig J, Przybilla R, Xiao Y, Hoefs J (2002) Excimer laser isotope-ratio-monitoring mass spectrometry for in situ oxygen isotope analysis. *Chem Geol* 182: 179–194
- Wilkinson JJ, Weiss DJ, Mason TF, Coles BJ (2005) Zinc isotope variation in hydrothermal systems: preliminary evidence from the Irish Midlands ore field. *Econ Geol* 100: 583–590

- Williams LB, Ferrell RE, Hutcheon I, Bakel AJ, Walsh MM, Krouse HR (1995) Nitrogen isotope geochemistry of organic matter and minerals during diagenesis and hydrocarbon migration. *Geochim Cosmochim Acta* 59: 765–779
- Williams LB, Hervig RL, Holloway JR, Hutcheon I (2001) Boron isotope geochemistry during diagenesis. Part I. Experimental determination of fractionation during illitization of smectite. *Geochim Cosmochim Acta* 65: 1769–1782
- Williams H, Peslier A, McCammon C, Halliday A, Levasseur S, Teutsch N, Burg JP (2005) Systematic iron isotope variations in mantle rocks and minerals: the effects of partial melting and oxygen fugacity. *Earth Planet Sci Lett* 235: 435–452
- Willmore CC, Boudreau AE, Spivack A, Kruger FJ (2002) Halogens of Bushveld Complex, South Africa:  $\delta^{37}\text{Cl}$  and Cl/F evidence for hydration melting of the source region in a back-arc setting. *Chem Geol* 182: 503–511
- Wong WW, Sackett WM (1978) Fractionation of stable carbon isotopes by marine phytoplankton. *Geochim Cosmochim Acta* 42: 1809–1815
- Wortmann UG, Bernasconi SM, Böttcher ME (2001) Hypersulfidic deep biosphere indicates extreme sulfur isotope fractionation during single-step microbial sulfate reduction. *Geology* 29: 647–650
- Wortmann UG, Chernyavsky B, Bernasconi SM, Brunner B, Böttcher ME, Swart PK (2007) Oxygen isotope biogeochemistry of pore water sulfate in the deep biosphere: dominance of isotope exchange reactions with ambient water during microbial sulfate reduction (ODP Site 1130). *Geochim Cosmochim Acta* 71: 4221–4232
- Wright I, Grady MM, Pillinger CT (1990) The evolution of atmospheric  $\text{CO}_2$  on Mars: the perspective from carbon isotope measurements. *J Geophys Res* 95: 14789–14794
- Wunder B, Meixner A, Romer R, Wirth R, Heinrich W (2005) The geochemical cycle of boron: constraints from boron isotope partitioning experiments between mica and fluid. *Lithos* 84: 206–216
- Wunder B, Meixner A, Romer R, Heinrich W (2006) Temperature-dependent isotopic fractionation of lithium between clinopyroxene and high-pressure hydrous fluids. *Contrib Miner Petrol* 151: 112–120
- Wunder B, Meixner A, Romer RL, Feenstra A, Schettler G, Heinrich W (2007) Lithium isotope fractionation between Li-bearing staurolite, Li-mica and aqueous fluids: an experimental study. *Chem Geol* 238: 277–290
- Xia J, Ito E, Engstrom DE (1997a) Geochemistry of ostracode calcite: Part I. An experimental determination of oxygen isotope fractionation. *Geochim Cosmochim Acta* 61: 377–382
- Xia J, Engstrom DE, Ito E (1997b) Geochemistry of ostracode calcite: Part 2. The effects of water chemistry and seasonal temperature variation on *Candona rawsoni*. *Geochim Cosmochim Acta* 61: 383–391
- Xiao Y, Hoefs J, van den Kerkhof AM, Simon K, Fiebig J, Zheng YF (2002) Fluid evolution during HP and UHP metamorphism in Dabie Shan, China: constraints from mineral chemistry, fluid inclusions and stable isotopes. *J Petrol* 43: 1505–1527
- Xiao Y, Zhang Z, Hoefs J, van den Kerkhof A (2006) Ultrahigh pressure rocks from the Chinese Continental Scientific Drilling Project: II Oxygen isotope and fluid inclusion distributions through vertical sections. *Contrib Miner Petrol* 152: 443–458
- Xie Q, Liu S, Evans D, Dillon P, Hintelmann H (2005) High precision Hg isotope analysis of environmental samples using gold trap-MC-ICP-MS. *J Anal At Spectrom* 20: 515–522
- Yamaguchi KE, Johnson CM, Beard BL, Ohmoto H (2005) Biogeochemical cycling of iron in the Archean-Paleoproterozoic Earth: constraints from iron isotope variations in sedimentary rocks from the Kapvaal and Pilbara cratons. *Chem Geol* 218: 135–169
- Yang J, Epstein S (1984) Relic interstellar grains in Murchison meteorite. *Nature* 311: 544–547
- Yang C, Telmer K, Veizer J (1996) Chemical dynamics of the “St Lawrence” riverine system:  $\delta\text{D}_{\text{H}_2\text{O}}$ ,  $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ ,  $\delta^{13}\text{C}_{\text{DIC}}$ ,  $\delta^{34}\text{S}_{\text{SO}_4}$  and dissolved  $^{87}\text{Sr}/^{86}\text{Sr}$ . *Geochim Cosmochim Acta* 60: 851–866
- Yapp CJ (1983) Stable hydrogen isotopes in iron oxides - isotope effects associated with the dehydration of a natural goethite. *Geochim Cosmochim Acta* 47: 1277–1287

- Yapp CJ (1987) Oxygen and hydrogen isotope variations among goethites ( $\alpha$ -FeOOH) and the determination of paleotemperatures. *Geochim Cosmochim Acta* 51: 355–364
- Yapp CJ (2007) Oxygen isotopes in synthetic goethite and a model for the apparent pH dependence of goethite-water  $^{18}\text{O}/^{16}\text{O}$  fractionation. *Geochim Cosmochim Acta* 71: 1115–1129
- Yapp CJ, Epstein S (1982) Reexamination of cellulose carbon-bound hydrogen  $\delta\text{D}$  measurements and some factors affecting plant-water D/H relationships. *Geochim Cosmochim Acta* 46: 955–965
- Yoshida N, Toyoda S (2000) Constraining the atmospheric  $\text{N}_2\text{O}$  budget from intramolecular site preference in  $\text{N}_2\text{O}$  isotopomers. *Nature* 405: 330–334
- Yoshida N, Hattori A, Saino T, Matsuo S, Wada E (1984)  $^{15}\text{N}/^{14}\text{N}$  ratio of dissolved  $\text{N}_2\text{O}$  in the eastern tropical Pacific Ocean. *Nature* 307: 442–444
- Young ED (1993) On the  $18\text{O}/16\text{O}$  record of reaction progress in open and closed metamorphic systems. *Earth Planet Sci Lett* 117: 147–167
- Young ED, Galy A (2004) The isotope geochemistry and cosmochemistry of magnesium. *Rev Miner Geochem* 55: 197–230
- Young ED, Rumble D (1993) The origin of correlated variations in in-situ  $^{18}\text{O}/^{16}\text{O}$  and elemental concentrations in metamorphic garnet from southeastern Vermont, USA. *Geochim Cosmochim Acta* 57: 2585–2597
- Young ED, Ash RD, England P, Rumble D (1999) Fluid flow in chondritic parent bodies: deciphering the compositions of planetesimals. *Science* 286: 1331–1335
- Young ED, Galy A, Nagahara H (2002) Kinetic and equilibrium mass-dependent isotope fractionation laws in nature and their geochemical and cosmochemical significance. *Geochim Cosmochim Acta* 66: 1095–1104
- Yung YL, Miller CE (1997) Isotopic fractionation of stratospheric nitrous oxide. *Science* 278: 1778–1780
- Yurimoto A, Krot A, Choi BG, Al  n J, Kunihiro T, Brearly AJ (2008) Oxygen isotopes in chondritic components. *Rev Miner Geochem* 68: 141–186
- Yurtsever Y (1975) Worldwide survey of stable isotopes in precipitation. Rep Sect Isotope Hydrol IAEA, November 1975, 40 pp
- Zaback DA, Pratt LM (1992) Isotopic composition and speciation of sulfur in the Miocene Monterey Formation: reevaluation of sulfur reactions during early diagenesis in marine environments. *Geochim Cosmochim Acta* 56: 763–774
- Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001) Trends, rhythms and aberrations in global climate 65 Ma to present. *Science* 292: 686–693
- Zeebe RE (1999) An explanation of the effect of seawater carbonate concentration on foraminiferal oxygen isotopes. *Geochim Cosmochim Acta* 63: 2001–2007
- Zeebe RE (2005) Stable boron isotope fractionation between dissolved  $\text{B}(\text{OH})_3$  and  $\text{B}(\text{OH})_4^-$ . *Geochim Cosmochim Acta* 69: 2753–2766
- Zeebe RE (2007) An expression for the overall oxygen isotope fractionation between the sum of dissolved inorganic carbon and water. *Geochem Geophys Geosys* 8: 10.1029/2007GC001663
- Zhang T, Krooss BM (2001) Experimental investigation on the carbon isotope fractionation of methane during gas migration by diffusion through sedimentary rocks at elevated temperature and pressure. *Geochim Cosmochim Acta* 65: 2723–2742
- Zhang J, Quay PD, Wilbur DO (1995) Carbon isotope fractionation during gas-water exchange and dissolution of  $\text{CO}_2$ . *Geochim Cosmochim Acta* 59: 107–114
- Zhang HF, et al. (2000) Recent fluid processes in the Kapvaal craton, South Africa: coupled oxygen isotope and trace element disequilibrium in polymict peridotites. *Earth Planet Sci Lett* 176: 57–72
- Zhang R, Schwarcz HP, Ford DC, Schroeder FS, Beddows PA (2008) An absolute paleotemperature record from 10 to 6 ka inferred from fluid inclusion D/H ratios of a stalagmite from Vancouver Island, British Columbia, Canada. *Geochim Cosmochim Acta* 72: 1014–1026
- Zheng YF (1991) Calculation of oxygen isotope fractionation in metal oxides. *Geochim Cosmochim Acta* 55: 2299–2307

- Zheng YF (1993a) Oxygen isotope fractionation in  $\text{SiO}_2$  and  $\text{Al}_2\text{SiO}_5$  polymorphs: effect of crystal structure. *Eur J Miner* 5: 651–658
- Zheng YF (1993b) Calculation of oxygen isotope fractionation in anhydrous silicate minerals. *Geochim Cosmochim Acta* 57: 1079–1091
- Zheng YF (1993c) Calculation of oxygen isotope fractionation in hydroxyl-bearing minerals. *Earth Planet Sci Lett* 120: 247–263
- Zheng YF, Hoefs J (1993) Carbon and oxygen isotopic variations in hydrothermal calcites. Theoretical modeling on mixing processes and application to Pb–Zn deposits in the Harz Mountains, Germany. *Miner Deposita* 28: 79–89
- Zheng YF, Fu B, Li Y, Xiao Y, Li S (1998) Oxygen and hydrogen isotope geochemistry of ultra-high pressure eclogites from the Dabie mountains and the Sulu terrane. *Earth Planet Sci Lett* 155: 113–129
- Zhu P, MacDougall JD (1998) Calcium isotopes in the marine environment and the oceanic calcium cycle. *Geochim Cosmochim Acta* 62: 1691–1698
- Zhu XK, O’Nions RK, Guo Y, Belshaw NS, Rickard D (2000a) Determination of natural Cu-isotope variations by plasma-source mass spectrometry: implications for use as geochemical tracers. *Chem Geol* 163: 139–149
- Zhu XK, O’Nions K, Guo Y, Reynolds BC (2000b) Secular variations of iron isotopes in North Atlantic Deep Water. *Science* 287: 2000–2002
- Zhu XK, et al. (2002) Mass fractionation processes of transition metal isotopes. *Earth Planet Sci Letters* 200: 47–62
- Ziegler K, Chadwick OA, Brzezinski MA, Kelly EF (2005a) Natural variations of  $\delta^{30}\text{Si}$  ratios during progressive basalt weathering. *Geochim Cosmochim Acta* 69: 4597–4610
- Ziegler K, Chadwick OA, White AF, Brzezinski MA (2005b)  $\delta^{30}\text{Si}$  systematics in a granitic saprolite, Puerto Rico. *Geology* 33: 817–820
- Zierenberg RA, Shanks WC, Bischoff JL (1984) Massive sulfide deposit at  $21^\circ\text{N}$ , East Pacific Rise: chemical composition, stable isotopes, and phase equilibria. *Bull Geol Soc Am* 95: 922–929
- Zimmer MM, Fischer TP, Hilton DR, Alvaredo GE, Sharp ZD, Walker JA (2004) Nitrogen systematics and gas fluxes of subduction zones: insights from Costa Rica arc volatiles. *Geochem Geophys Geosys* 5: Q05J11, doi:10.1029/2003GC000651
- Zinner E (1998) Stellar nucleosynthesis and the isotopic composition of presolar grains from primitive meteorites. *Ann Rev Earth Planet Sci* 26: 147–188



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