***Asignatura*: Geología Isotópica**

Carrera: *Licenciatura en Ciencias Geológicas*

Carácter: *Electiva*

Año: *-*

Cuatrimestre: *1C*

Frecuencia de dictado: *Anual*

Profesor

Héctor Ostera *(haostera@dtplaboratorios.com)*

GEOLOGÍA ISOTÓPICA

DICTADO 2023

Objetivo de la materia

El objetivo de la materia es que los estudiantes aprendan y se familiaricen con los fundamentos de la geoquímica isotópica y las aplicaciones de los isótopos estables e inestables en geología.

La materia está dividida en dos bloques, uno referido a isótopos ambientales y otra asociada a geocronología, isótopos radiactivos y radigénicos.

La idea es que al final de la materia hayan comprendido los principios básicos, puedan leer y entender críticamente cualquier trabajo sobre el tema, procesar información que puedan recibir de diferentes laboratorios y eventualmente, generar sus propios datos si les interesa.

Metodología

La metodología de enseñanza incluye:

a) Clases teóricas

Exponen la información básica y avanzada de los diferentes tópicos, resumen el conocimiento hasta la fecha desde muchas fuentes, provee estructuras para ayudar a los estudiantes a aprender más efectivamente

b) Clases de problemas - Discusiones

Da a los estudiantes oportunidad de aplicar principios, formular problemas y aprender a evaluar la evidencia desde su punto de vista y desde el de otros.

La participación en las discusiones ayuda a los estudiantes a establecer relaciones entre conceptos hablando y explicando, resumiendo y preguntándose acerca de las relaciones entre hechos y evidencias.

c) Aprendizaje experimental

Incluye el trabajo en laboratorio, campo y el desarrollo de trabajos en conjunto. Estas experiencias permiten a los estudiantes describir y entender problemas concretos y específicos, como asimismo enfrentar las complicaciones intrínsecas que implica el uso de equipamiento.

d) Casos tipo

Se utilizarán para representar un tipo particular de problema, con datos reales. Comprende la adquisición, reprocesamiento, uso de la información y aplicación de aspectos teóricos a la resolución de un problema.

Modalidad de la materia: Teóricas y Prácticas (Problemas).

Carga horaria: 96 horas

Evaluación virtual: Dos exámenes parciales y final. Para aprobar los prácticos, los estudiantes deberán realizar y presentar individualmente un trabajo monográfico, después de finalizado el dictado de cada bloque. Los mismos serán remitidos al profesor para su evaluación y expuestos en presencia de toda la clase. Allí serán sometidos a discusión por el profesor y el conjunto de participantes. De ser necesario, existe la posibilidad de dos exámenes recuperatorios eventuales correspondientes a cada bloque, que se tomarán al finalizar la cursada. .

El examen final virtual será presentado y acordado con el profesor, en fecha y aula virtual a determinar. Tendrá carácter público para todos los cursantes.

PROGRAMA

1. Geología Isotópica, definición y orígenes.

2. Estructura atómica de la materia. Origen de los elementos. Isótopos estables e inestables. Fraccionamiento isotópico. Constantes de equilibrio en las reacciones de intercambio isotópico. Mecanismos de decaimiento y transformaciones radiactivas.

3. Análisis instrumental. Técnicas de medición de abundancia relativa y absoluta de los isótopos. Espectrometría de masas.

4. Isotopos estables del oxígeno y el hidrógeno en la hidrosfera. Distribución y ciclo en la naturaleza. La notación delta. Interpretación de isótopos ambientales en combinación con hidroquímica en hidrología subterránea. Técnicas isotópicas aplicadas al desarrollo y manejo de los recursos hídricos.

5. Isótopos estables del azufre, carbono y nitrógeno en la hidrósfera y la litósfera. Distribución y ciclo en la naturaleza. Isótopos estables del oxígeno e hidrógeno en la litosfera. Utilización de isótopos ambientales como trazadores y monitores ambientales. Técnicas isotópicas aplicadas al estudio de cambios pasados y presentes en la hidrosfera y atmósfera (Global Change). Cronoestratigrafía isotópica

6. Geotermometría isotópica. Aplicación de los isótopos estables como geotermómetros. Geotermia. Utilización de los isótopos estables en el modelado de sistemas geotérmicos.

7. Geocronología. Principios básicos. Ecuaciones generales. Métodos radimétricos. de acumulación. Generalidades.

8. Método K-Ar: Principios y técnicas experimentales. Temperaturas de bloqueo. Isocronas K-Ar. Datación de rocas ígneas, metamórficas y sedimentarias. Limitaciones. Correlación con paleomagnetismo. Método $^{40}Ar/^{39}Ar$: Principios.

Técnicas experimentales. Difusión y “recoil”. Desgasificado por etapas. Espectro de edades. Isocronas. Historia térmica. Exceso de ^{40}Ar. Ventajas y limitaciones.

9. Método Rb /Sr. Principios y metodología. Geoquímica del Rb y Sr. Isocronas. Programas de cálculo. Geología isotópica del Sr en meteoritos . Evolución del Sr en la Tierra. Datación de rocas ígneas, metamórficas y sedimentarias. Sistemas abiertos y cerrados. Limitaciones. Evolución de los isótopos del Sr en el agua de mar.

10. Método Sm/Nd. Principios y metodología. Geoquímica del Sm y Nd. Isocronas. Evolución del Nd en el sistema solar y la tierra. Edades modelo CHUR y DM. Edades de proveniencia. Aplicaciones del método en rocas ígneas, metamórficas y sedimentarias.

11.Método Lu/Hf. Geoquímica del Lu y el Hf. Evolución del Hf en el manto y la corteza. Método Re-Os. Geoquímica del Re y el Os. Evolución del Os en el manto y la corteza. Aplicación en depósitos minerales. Otros métodos de acumulación: K-Ca, La-Ce y La-Ba. Principios y técnicas experimentales. Aplicaciones.

12. Métodos isotópicos. U-Th-Pb Principios y técnicas experimentales. Geoquímica del U, Th y Pb. Las series de decaimiento del U y Th. Diagrama de concordia. Datación de rocas ígneas, sedimentarias y metamórficas. Modelos. Datación de granos individuales de zircón. Método Pb - Pb. Isocronas. Método del plomo común. Modelo Holmes - Houtermans. Modelos de dos etapas, Modelos complejos. Aplicaciones a medio ambiente y prospección de yacimientos.

13. Isótopos de gases nobles: He, Ar, Ne y Xe. Principios y técnicas experimentales. Evolución de la atmósfera terrestre.

14. Utilización de los isótopos del Sr, Nd, Pb, He y Hf en petrología. Combinación con isótopos estables. Comportamiento en la evolución magmática (Modelos CF, ACF). Procesos de mezcla de componentes y modelado. Ejemplos sudamericanos y argentinos.

15. Geodinámica isotópica. Evolución temporal de la corteza y el manto terrestre. La acreción cortical. El manto primitivo. Isótopos en el estudio de la génesis y evolución del sistema solar.

16. Aplicación de isótopos radigénicos en metalogénesis de depósitos minerales.

17. Métodos radimétricos de decaimiento: nucleidos cosmogénicos. Métodos ^{14}C y Tritio. Principios y técnicas experimentales. ^{14}C: Variaciones seculares, efecto reservorio, datación de carbonatos y aguas subterráneas. Tritio en la atmósfera. Métodos ^{26}Al y ^{10}Be.Producción en la atmósfera. Tiempos de residencia. Datación de sedimentos. ^{10}Be en rocas volcánicas. Datación de hielo y aguas subterráneas con nucleidos cosmogénicos.

18. Desequilibrio radiactivo en series del U. Fundamentos, técnicas experimentales y principales métodos: ^{234}U, ^{230}Th, ^{210}Pb. Aplicaciones en procesos de corto término: evolución de cámaras magmáticas y dorsales oceánicas.

19. Daño por radiación: Trazas de Fisión. Principios y técnicas experimentales. Temperaturas de cierre y aplicaciones. Tasas de ascenso y subsidencia. Termoluminiscencia y ESR. Principios y técnicas experimentales. Aplicaciones. Otros métodos de datación (racemización de aminoácidos, métodos químicos).

20. El tiempo geológico. Edades. Escalas.

21. Técnicas isotópicas aplicada a estudios del medio ambiente. Isótopos de gases nobles aplicados como trazadores en estudios ambientales. Isótopos artificiales. Contaminación radiactiva del ambiente continental y marino. Conceptos básicos de seguridad radiológica. Impacto ambiental de la liberación de radionucleidos en el medio acuoso. Disposición de residuos radiactivos. Aplicaciones combinadas en atmósfera, hidrosfera y litosfera.

23. Trazadores isotópicos naturales y artificiales en geología del petróleo. Metodologías y conceptos fundamentales. Modelado en inyección de trazadores radiactivos naturales y artificiales. Determinación de permeabilidad y porosidad. Producción y recuperación secundaria. Localización de fracturas. Almacenamiento y transporte de fluidos. Pérdidas y filtraciones.

24. Disposición de residuos radiactivos. Técnicas isotópicas aplicadas al estudio de sitios de disposición final. Reactores naturales. Estado del arte y nuevas aplicaciones y metodologías en geología isotópica.

BIBLIOGRAFÍA

Albarede, F. 2009. Geochemistry: An Introduction. Cambridge University Press, pp. 355.

Allègre, C. J., P. Sarda and T. Staudacher. 1993. Speculations about the cosmic origin of He and Ne in the interior of the Earth, Earth Planet. Sci. Lett., 117, 229-233, 1993.

Allègre, C. J.& C. Sutcliffe. 2008. Isotope Geology.Cambridge University Press. 512 pp.

Allégre, C. J., and J. M. Luck. 1980. Osmium isotopes as petrogenic and geologic tracers, Earth Planet. Sci. Lett., 48: 148-154.

Amelin, Y. 2005. Meteorite phosphates show constant ^{176}Lu decay rate since 4557 million years ago, Science, 310:

Amelin, Y. and Krot, A. N. 2007. Pb isotopic age of the Allende chondrules, Meteoritics and Planetary Science, 42:1321–1335.

Amelin, Y., Krot, A. N., Hutcheon, I. D. and Ulyanov, A. A. 2002. Lead isotopic ages of chondrules and calcium-aluminum-rich inclusions, Science, 297: 1678–1683.

Armit, R.J., Betts, P.G., Schaefer, B.F., Pankhurst, M.J. and Giles, D. 2014. Provenance of the Early Mesoproterozoic Radium Creek Group in the northern Mount Painter Inlier: correlating isotopic signatures to inform tectonic reconstructions. Precambrian Research 243: 63–87.

Arne, D. C., Bierlein, F. P., Morgan, J. W., and Stein, H. J. 2001. Re-Os dating of sulfides associated with gold

Baker, J., Bizzarro, M., Wittig, N., Connolly, J. N. and Haack, H. 2005. Early planetesimal melting from an age of 4.5662 Gyr for differentiated meteorites, Nature, 436: 1127–1131.

Belousouva, E.A., Reid, A.J., Griffin, W.L. and O'Reilly, S.Y. 2009. Rejuvenation vs. recycling of Archean crust in the Gawler Craton, South Australia: evidence from U–Pb and Hf isotopes in detrital zircon. Lithos, 113(3–4): 570–582.

Bau, M. and Koschinsky, A. 2006. Hafnium and neodymium isotopes in seawater and in ferromanganese crusts: The "element perspective." Earth and Planetary Science Letters, 241: 952–961.

Baskaran, M. 2012. Handbook of Environmental Isotope Geochemistry. Springer, 974 pp.

Ben Othman, D.,White,W. M. and Patchett, J. 1989. The geochemistry of marine sediments, island arc magma genesis, and crust-mantle recycling, Earth and Planetary Science Letters, 94: 1–21.

Bennett, V. C. and DePaolo, D. J. 1987. Proterozoic crustal history of the western United States as determined by neodymium isotope mapping. Bulletin of the Geological Society of America, 99: 674–685.

Bennett, V. C., Brandon, A. D. and Nutman, A. P. 2007. Coupled ^{142}Nd-^{143}Nd isotopic evidence for Hadean mantle dynamics, Science, 318: 1907–1910.

Bigeleisen, J. and M. G. Mayer. 1947. Calculation of equilibrium constants for isotopic exchange reactions, J. Chem. Phys., 15: 261-267.

Bizzarro, M., Baker, J. A., Haack, H., Ulfbeck, D. and Rosing, M. 2003. Early history of Earth's crust-mantle system

Bizzarro, M., Connelly, J. N., Thrane, K. and Borg, L. E. 2012. Excess hafnium-176 in meteorites and the early Earth

Blichert-Toft, J. and Albarède, F. 1997. The Lu-Hf isotope geochemistry of chondrites and the evolution of the

Blichert-Toft, J. and Albarède, F. 2008. Hafnium isotopes in Jack Hills zircons and the formation of the Hadean crust. Earth and Planetary Science Letters, 265: 686–702.

Boltwood, B. B. 1907. Ultimate disintegration products of the radioactive elements; Part II, Disintegration products of

Bourdon, B., Turner, S., Henderson, G.M. and Lundstrom, C.C. 2003. Introduction to U-series geochemistry. Reviews in Mineralogy and Geochemistry 52(1): 1–21.

Bouvier, A., Vervoort, J. D. and Patchett, P. J. 2008. The Lu-Hf and Sm-Nd isotopic composition of CHUR; constraints

Bowen, R. 1988. Isotopes in the Earth Sciences, Barking (Essex): Elsevier Applied Science Publishers.

Bowring, J. F., N. M. McLean, and S. A. Bowring. 2011, Engineering cyber infrastructure for U-Pb geochronology: Tripoli and U-Pb_Redux, Geochem. Geophys. Geosyst., 12, Q0AA19,.

Boyd, S. R. and C. T. Pillinger. 1994. A prelimiary study of ^{15}N/^{14}N in octahedral growth form diamonds.Chem. Geol. 116: 43-59.

Boyd, S. R., F. Pineau and M. Javoy. 1994. Modelling the growth of natural diamonds. Chem. Geol.116: 29-42.

Boyet, M. and Carlson, R. L. 2005. ^{142}Nd evidence for early (>4.3 Ga) global differentiation of the silicate Earth, Science, 309: 576–581.

Boyet, M. and Carlson, R. L. 2006. A new geochemical model for the Earth's mantle inferred from ^{146}Sm–^{142}Nd systematics, Earth and Planetary Science Letters, 250: 254–268.

Boyet, M., Blichert-Toft, J., Rosing, M., Storey, M., Telouk, P. and Albarede, F. 2003. ^{142}Nd evidence for early Earth differentiation, Earth and Planetary Science Letters, 214: 427–442.

Boyet, M., Blichert-Toft, J., Rosing, M., Storey, M., Telouk, P. and Albarede, F. 2003. ^{142}Nd evidence for early Earth differentiation. Earth and Planetary Science Letters, 214: 427–442.

Brandon, A. D., Walker, R. J., Morgan, J. W., Norman, M. D. and Prichard, H. M. 1998. Coupled ^{186}Os and ^{187}Os evidence for core-mantle

interaction, Science, 280: 1570–1573.

Braun, J., van der Beek, P. and Batt, G. 2006. Quantitative Thermochronology: Numerical Methods for the Interpretation of Thermochronological Data. Cambridge University Press, pp. 270.

Broecker, W. and V. Oversby. 1971. Chemical Equilibria in the Earth, New York: McGraw-Hill.

Burton, K. W. and Vance, D. 2000. Glacial–interglacial variations in the neodymium isotope composition of seawater in the Bay of Bengal recorded by planktonic foraminifera. Earth and Planetary Science Letters, 176: 425–441,

Burton, K. W., Gannoun, A. and Parkinson, I. J. 2010. Climate driven glacial–interglacial variations in the osmium isotope composition of seawater recorded by planktic foraminifera. Earth and Planetary Science Letters, 295: 58–68.

Caro, G. and Bourdon, B. 2010. Non-chondritic Sm/Nd ratio in the terrestrial planets: Consequences for the geochemical evolution of the mantle crust system, Geochimica et Cosmochimica Acta, 74: 3333–3349.

Caro, G., Bourdon, B., Halliday, A. N. and Quitte, G. 2008. Super-chondritic Sm/Nd ratios in Mars, the Earth, and the Moon. Nature, 452: 336–339,

Carpentier, M., Chauvel, C. and Mattielli, N. 2008. Pb-Nd isotopic constraints on sedimentary input into the Lesser Antilles arc system. Earth and Planetary Science Letters, 272: 199–211.

Cates, N. L., Ziegler, K., Schmitt, A. K. and Mojzsis, S. J. 2013. Reduced, reused and recycled: Detrital zircons define a maximum age for the Eoarchean (ca. 3750–3780 Ma) Nuvvuagittuq Supracrustal Belt, Québec (Canada). Earth and Planetary Science Letters, 362: 283–293,

Cerling, T. E., Y. Wang and J. Quade. 1993. Expansion of C4 ecosystems as an indicator of global ecological change in the late Miocene, Nature, 361, 344-345.

Chan, L. H., J. M. Edmond, G. Thompson and K. Gillis. 1992. Lithium isotopic composition of submarine basalts: implications for the lithium cycle of the oceans. Earth Planet. Sci. Lett. 108:151-160.

Chan, L.-H. and J. M. Edmond. 1988. Variation of lithium isotope composition in the marine environment: a preliminary report. Geochim. Cosmochim. Acta. 52: 1711-1717.

Chaussidon, M. and A. Jambon. 1994. Boron content and isotopic composition of oceanic basalts: geochemical and cosmochemical implications. Earth Planet. Sci. Lett. 121: 277-291.

Chaussidon, M. and B. Marty. 1995. Primitive boron isotope composition of the mantle. Science.269: 383-266.

Chaussidon, M. and F. Albarede. 1992. Secular boron isotope variations in the continental crust: anion microprobe study. Earth Planet. Sci. Lett. 108: 229-241.

Chaussidon, M., F. Albarède and S. M. F. Sheppard. 1987. Sulphur isotope heterogeneity in themantle from ion microprobe measurements of sulphide inclusions in diamonds. Nature. 330: 242-244.

Chaussidon, M., F. Albarede and S. M. F. Sheppard. 1989. Sulphur isotope variations in the mantlefrom ion microprobe analyses of micro-sulphide inclusions. Earth Planet. Sci. Lett. 92: 144-156.

Chaussidon, M., S. M. F. Sheppard and A. Michard. 1991. Hydrogen, sulfur and neodymium isotope variations in the mantle beneath the EPR at 12°50´´N. in Stable Isotope Geochemistry: A Tribute to Samuel Epstein, ed. H. P. Taylor, J. R. O'Neil and I. R. Kaplan. 325-338. San Antonio: Geochemical Society.

Cheng, H., Zhang, C., Vervoort, J. D., Li, X., Li, Q., Zheng, S. and Cao, D. 2011. Geochronology of the transition of eclogite to amphibolite facies metamorphism in the North Qinling orogen of central China. Lithos, 125: 969–983,

Chiaradia, M., Schaltegger, U., Spikings, R.,Wotzlaw, J.-F. and Ovtcharova, M. 2013. How accurately can we date the duration of magmatic-hydrothermal events in porphyry systems? Economic Geology 108(4): 565–584.

Chiba, H., T. Chacko, R. N. Clayton and J. R. Goldsmith. 1989. Oxygen isotope fractionations involving diopside, forsterite, magnetite, and calcite: application to geothermometry. Geochim. Cosmochim. Acta. 53: 2985-2995.

Clark, I.D. & P. Fritz. 1997. Environmental isotopes in hydrogeology. Lewis Publishers, Nwe York. 326 pp.

Clark, W. B, M. A. Beg, and H. Craig. 1969. Excess ^{3}He in the sea: evidence for terrestrial primor-dial helium, Earth Planet. Sci. Lett., 6: 213-230, 1969.

Clayton, R.N. (1993) Oxygen isotopes in meteorites. Annual Review of Earth and Planetary Sciences21, 115-149.

Condie, K. C. and Aster, R. C. 2010. Episodic zircon age spectra of orogenic granitoids: The supercontinent connection and continental growth. Precambrian Research, 180: 227–236.

Condon, D.J., McLean, N., and Noble, S.R. 2010. Isotopic Composition (^{238}U/^{235}U) of some commonly used Uranium reference materials. Geochimica et Cosmochimica Acta, v. 74, p. 7127-7143.

Condon, D.J., McLean, N., Schoene, B., Bowring, S.A., and Parrish, R.R. 2015. Metrology and Traceability of U-Pb Isotope Dilution Geochronology (EARTHTIME Tracer Calibration Part I). Geochimica et Cosmochimica Acta

Corfu, F. 2012. A century of U–Pb geochronology: the long quest towards concordance. Geological Society of America Bulletin 125(1–2): 33–

47.

Craig, H. 1963. The isotopic composition of water and carbon in geothermal areas, in Nuclear Geology on Geothermal Areas, ed. by E. Tongiorgi, p. 17-53, Pisa: CNR Lab. Geol. Nucl.

Crank, J. 1975. The Mathematics of Diffusion. Oxford Press, 2nd edn, 414 pp.

Creaser, R. A., D. A. Papanastassiou and G. J. Wasserburg. 1991. Negative thermal ion mass spectrometry of osmium, rhenium, and iridium. Geochim. Cosmochim. Acta. 55: 397-401.

Creaser, R. A., Papanastassiou, D. A. andWasserburg, G. J. 1991. Negative thermal ion mass spectrometry of osmium,

Criss, R. E. and H. P. Taylor. 1986. Meteoric-hydrothermal systems, in Stable Isotopes in High Temperature Geological Processes, Reviews in Mineralogy 16, ed. by J. W. Valley, H. P. Taylor and J. R.O'Neil, p. 373-424, Washington: Mineral. Soc. Am., Washington.

Cummin, V.M., Selby, D., Lillis, P.G. and Lewan, M.D. 2014. Re–Os geochronology and Os isotope fingerprinting of petroleum sourced from a Type I lacustrine kerogen: insights from the natural Green River petroleum system in the Uinta Basin and hydrous pyrolysis experiments. Geochimica et Cosmochimica Acta 138: 32–56.

Dansgaard, W. 1964. Stable isotopes in precipitation. Tellus, 16, 436-463.

Deloule, E., F. Albarede and S. M. F. Sheppard. 1991. Hydrogen isotope heterogeneity in the mantle from ion probe analysis of amphiboles from ultramafic rocks. 105: 543-553.

DeNiro, M. J. 1987. Stable Isotopy and Archaeology, Am. Scientist, 75: 182-191.

DeNiro, M. J. and C. A. Hasdorf. 1985. Alteration of $1^{5}N/^{14}$ N and $^{13}C/^{12}C$ ratios of plant matter during the initial stages of diagenesis: studies utilizing archeological specimens from Peru, Geochim. Cosmochim. Acta, 49, 97-115.

DeNiro, M. J. and S. Epstein. 1978. Influence of diet on the distribution of carbon isotopes in animals, Geochim. Cosmochim. Acta, 42: 495-506.

DeNiro, M. J. and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals, Geochim. Cosmochim. Acta, 45> 341-351.

DePaolo, D. and Wasserburg, G. 1976. Inferences about magma sources and mantle structure from variations of $^{143}Nd/^{144}Nd$. Geophysical Research Letters, 3: 743–746,

DePaolo, D. J. 1981. Neodymium isotopes in the Colorado Front Range and crust mantle evolution in the Proterozoic, Nature, 291, 193-196.

DePaolo, D. J. 1988. Neodymium Isotope Geochemistry, an Introduction, Berlin: Springer-Verlag.

DePaolo, D.J. 1981. Trace element and isotopic effects of combined wallrock assimilation and fractional crystallisation. Earth and Planetary Science Letters 53(2): 189–202.

DePaolo, D.J. 1983. The mean life of continents: estimates of continent recycling rates from Nd and Hf isotopic data and implications for mantle structure. Geophysical Research Letters 90: 263–271.

DePaolo, D.J., Linn, A.M. and Schubert, G. 1991. The continental crustal age distribution: methods of determining mantle separation ages from Sm–Nd isotopic data and application to the southwestern United States. Journal of Geophysical Research 96(B2): 2071–2088.

Dickin, A. P., Cerium isotope geochemistry of ocean island basalts, Nature, 326: 283-284, 1987.

Dickin, A.P. 2008. Radiogenic Isotope Geochemistry. Cambridge University Press, pp. 492.

Diffusion of radiogenic and excess ^{40}Ar in hornblende revealed by 40Ar39Ar age spectrum analysis. Geochimica et Cosmochimica Acta, 44: 2005–2020.

Dodson, M. H. 1973. Closure temperature in cooling geochronological and petrological systems, Contributions to Mineralogy and Petrolology, 40: 259–274.

Eldridge, C. S., W. Compston, I. S. Williams, J. W. Harris and J. W. Bristow. 1991. Isotope evidence for the involvement of recycled sediment in diamond formation. Nature. 353: 649-653.

Emiliani, C. 1955. Pleistocene temperatures, J. Geol., 63, 538-578.

Epov, V.N., Malinovskiy, D., Vanhaecke, F., Begue, D. and Donard, O.F.X. 2011. Modern mass spectrometry for studying mass-independent fractionation of heavy stable isotopes in environmental and biological sciences. Journal of Analytical Atomic Spectrometry 26: 1142–1156.

Esser, B. K. and K. K. Turekian. 1993. The osmium isotopic composition of the continental crust. Geochimica et Cosmochimica Acta. 57: 3093-3104.

Farley, K. A. and R. J. Poreda. 1993., Mantle neon and atmospheric contamination, Earth Planet. Sci. Lett., 114, 325-339.

Faure, G. 1986. Principles of Isotope Geology, 2 nd ed., New York: Wiley & Sons.

Faure, G. and Mensing, T.M. 2005 Isotopes: Principles and Applications. Wiley, pp. 896.

Ferronsky, V. I., and V. A. Polyakov. 1982. Environmental Isotopes in the Hydrosphere, Chichester: John Wiley and Sons.

Fitzgerald, P.G. and Gleadow, A.J.W. 1988. Fission track geochronology, tectonics and structure of the transantarctic mountains in Northern Victoria Land, Antarctica. Chemical Geology 73(2): 169–198.

Fogel, M. L., and M. L. Cifuentes. 1993. Isotope Fractionation during Primary Production, in Organic Geochemistry: Principles and Applications edited by M. H. Engel and S. A. Macko, p. 73-98. New York: Plenum.

Gast, P. W. 1960. Limitations on the composition of the upper mantle, J. Geophys. Res., 65: 1287-1297.

Gleadow, A.J.W. 1983. Fission track analysis: a new tool for the evaluation of thermal histories and hydrocarbon potential. APEA Journal 23(1): 93–102.

Goldhaber, M., S. E. Church, B. R. Doe, C. Taylor, J. C. Brannon, and C. A. Gent. 1995. Sources and transport paths for MVT ore deposit lead and sulfur in the midcontinent of the U.S.A. in International Field Conference on Carbonate-Hosted Lead-Zinc Deposits - Extended Abstracts. D. L. Leach and M. B. Goldhaber (ed.) p.111-114. Littleton (CO): Society of Economic Geologists.

Gross, J.H. 2012. Mass Spectrometry: A Text Book. Springer, pp. 753.

Harmon, R.S., Hoefs, J. Oxygen isotope heterogeneity of the mantle deduced from global 18O systematics of basalts from different geotectonic settings. Contr. Mineral. and Petrol. 120, 95–114 (1995).

Harrison, T. M. and McDougall, I. 1980. Investigations of an intrusive contact, northwest Nelson, New Zealand–II.

Harrison, T. M. and McDougall, I. 1981. Excess ^{40}Ar in metamorphic rocks from Broken Hill, New South Wales: implications for 40Ar/39Ar age spectra and the thermal history of the region. Earth and Planetary Science Letters, 55: 123–149,

Harrison, T. M., Duncan, I. and McDougall, I. 1985. Diffusion of 40Ar in biotite: temperature, pressure and compositional effects, Geochimica et Cosmochimica Acta, 49: 2461–2468.

Hart, S.R. 1984.A large-scale isotopic anomaly in the Southern Hemisphere mantle. Nature 309: 753–757.

Hauri, E. H. and S. R. Hart. 1993. Re-Os isotope systematics of HIMU and EMII oceanic island basalts from the south Pacific Ocean. Earth Planet. Sci. Lett. 114: 353-371.

Hawkesworth, C. J. and Kemp, A. I. S. 2006. Using hafnium and oxygen isotopes in zircons to unravel the record of crustal evolution. Chemical Geology, 226: 144–162.

Hawkesworth, C. J., Dhuime, B., Pietranik, A. B., Cawood, P. A., Kemp, A. I. S. and Storey, C. D. 2010. The generation and evolution of the continental crust. Journal of the Geological Society, 167: 229–248.

Hayes, J. D., J. Imbrie and N. J. Shackleton. 1976. Variations in the Earth's orbit: pacemaker of the ice ages, Science, 194, 1121-1132.

Heizler, M. T. and Harrison, T. M. 1988. Multiple trapped argon isotope components revealed by 40Ar39Ar isochron analysis. Geochimica et Cosmochimica Acta, 52: 1295–1303,

Heming, N. G. and G. N. Hanson. 1992. Boron isotopic composition and concentration in modern marine carbonates. Geochim. Cosmochim. Acta. 56: 537-543.

Hiess, J., Condon, D.J., Noble, S.R., and McLean, N. 2012 Absolute ^{238}U/^{235}U determinations for use in U-daughter Geochronology. Science, v. 335, p. 1610-1614.

Hirt, B., Herr, W. and Hoffmester, W. 1963. Age determinations by the rhenium-osmium method. In: Radioactive Dating, pp. 35–44. Vienna: Internation. Atom Energy Agency.

Hirt, B., W. Herr and W. Hoffmester. 1963. Age determinations by the rhenium-osmium method.in Radioactive Dating, ed. 35-44. Vienna: Internation. Atom Energy Agency.

Hoefs, J. 2015. Stable Isotope Geochemistry. Springer, pp. 389.

Hofmann, A. W. and W. M. White. 1982. Mantle plumes from ancient oceanic crust. Earth Planet.Sci. Lett. 57: 421-436.

Hofmann, A.W. 1997. Mantle geochemistry: the message from oceanic volcanism. Nature 385: 219–229.

Honda, M., M. I., D. Patterson, A. Doulgeris and D. Clague, Possible solar noble-gas component in Hawaiian basalts, Nature, 349, 149-151, 1991.

Huang, Y., Chubakov, V., Mantovani, F., Rudnick, R. L. and McDonough,W. F. 2013. A reference Earth model for the heat-producing elements and associated geoneutrino flux. Geochemistry, Geophysics, Geosystems, 14: 2003–2029,

Huh, C.-A. and T.-L. Ku. 1984. Radiochemical observations on manganese nodules from three sedimentaryenvironments in the north Pacific, Geochim. Cosmochim. Acta, 48. 951-964.

Imbrie, J. 1985. A theoretical framework for the Pleistocene ice ages, J. Geol. Soc. Lond., 142, 417-432.

Imbrie, J., J. D. Hayes, D. G. Martinson, A. McIntyre, A. Mix, et al., 1985. The orbital theory of Pleistocene climate: support from a revised chronology of the marine δ 18O record, in Milankovitch and Climate, Part 1, edited by A. L. Berger, J. Imbrie, J. Hayes, G. Kukla and B.Saltzman, p. 269-305..

Ishikawa, T. and E. Nakamura. 1992. Boron isotope geochemistry of the oceanic crust from DSDP/ODP Hole 504B. Geochim. Cosmochim. Acta. 56: 1633-1639.

Ishikawa, T. and E. Nakamura. 1993. Boron isotope systematics of marine sediments. Earth PlanetSci. Lett. 117: 567-580.

Jackson, S.E., Pearson, N.J., Griffin, W.L. and Belousova, E.A. 2004. The application of laser ablation-inductively coupled plasma-mass

spectrometry to in situ U–Pb zircon geochronology. Chemical Geology 211(1): 47–69.

Jacobsen, S. B. and Wasserburg, G. J. 1984. Sm-Nd isotopic evolution of chondrites and achondrites, II. Earth and Planetary Science Letters, 67: 137–150.

Javoy, M. 1977. Stable isotopes and geothermometry, J. Geol. Soc. Lond., 133, 609-639.

Javoy, M. and F. Pineau. 1991. The volatile record of a "popping" rock from the Mid-Atlantic Ridge at 14° N: chemical and isotopic composition of the gas trapped in the vesicles, Earth Planet. Sci. Lett., 107, 598-611.

Jicha, B.R., Singer, B.S., Sobol, P., 2016. Re-evaluation of the ages of $^{40}Ar/^{39}Ar$ sanidine standards and supereruptions in the western US using a Noblesse multi-collector mass spectrometer. Chemical Geology, v. 431, p. 54-66.

Jouzel, C., C. Lorius, J. R. Perfit, C. Genthon, N.I. Barkov, V. M. Kotlyakov, and V. N. Petrov.1987. Vostok ice core: a continuous isotope temperature record over the last climatic cycle (160,000 years), Nature, 329: 403-403.

Kawabe, I. 1979. Calculation of oxygen isotopic fractionation in quartz-water system with special reference to the low temperature fractionation, Geochim. Cosmochim. Acta, 42: 613-621.

Kelley, S. 2002. Excess argon in K–Ar and Ar–Ar geochronology. Chemical Geology 188(1–2): 1–22.

Koppers, A.A.P., 2002. ArArCALC—software for$^{40}Ar/^{39}Ar$ age calculations. Computers & Geosciences v. 28, i. 5, p. 605-619.

Kuiper, K.F., Deino, A., Hilgen, F.J., Krijgsman, W., Renne, P.R., and Wijbrans, J.R., 2008. Synchronizing rock clocks of Earth history. Science, v. 320 i. 5875, p. 500-504.

Kuiper, Y.D. 2002. The interpretation of inverse isochron diagrams in 40Ar/39Ar geochronology. Earth and Planetary Science Letters 203(1): 499–506.

Kurz, M. D. 1987. In situ production of terrestrial cosmogenic helium and some applications to gechronology, Geochim. et Cosmochim. Acta, 50: 2855–2862.

Kurz, M. D., W. J. Jenkins, and S. R. Hart. 1982. Helium isotopic systematics of oceanic islands and mantle heterogeneity, Nature, 297: 43-47.

Kyser, K. T. 1986. Stable isotope variations in the mantle, in Stable Isotopes in High Temperature Geologic Processes, edited by J. W. Valley, H. P. Taylor and J. R. O'Neil, p. 141-164, Washington: Mineral. Soc. Am.

Lawrence, J. R. and H. P. Taylor. 1972. Hydrogen and oxygen isotope systematics in weathering profiles, Geochim. Cosmochim. Acta, 36, 1377-1393.

Lawrence, J. R. and J. R. Meaux. 1993. The stable isotopic composition of ancient kaolinites of North America, in Climate Change in Continental Isotopic Records, Geophysical Monograph 78, edited by P. K. Swart, K. C. Lohmann, J. McKenzie and S. Savin, p. 249-261.Washington: AGU.

Lee, J.K.W., Onsott, T.C., Casman, K.V., Cumbest, R.J. and Johnson, D. 1991. Incremental heating of hornblende in vacuo: implications for $^{40}Ar/^{39}Ar$ geochronology and the interpretation of thermal histories. Geology 19(9): 872–876.

Letters, 48: 148–154.

Linares, E. 2008. Geología Isotópica. INHEIS, Edición CD ROM.

Luck, J.-M., Bircke, J.L. and Allegre, C.J. 1980. $^{187}Re–^{188}Os$ systematics in meteorites: early chronology of the solar system and the age of the galaxy. Nature 283: 256–259.

Luck, J.-M., J.-L. Birck and C. J. Allegre. 1980. ^{187}Re -^{187}Os systematics in meteorites: Early chronology of the solar system and age of the Galaxy. Nature. 283: 256-259.

Ludwig, K.R. 1980. Calculation of uncertainties of U–Pb isotope data. Earth and Planetary Science Letters 46: 212–220.

Ludwig, K.R. 1998. On the treatment of concordant uranium–lead ages. Geochimica et Cosmochimica Acta 62(4): 665–676.

Ludwig, K.R. 2000. Decay constant errors in U–Pb concordia-intercept ages. Chemical Geology 166(3–4): 315–318.

Lupton J. E. and H. Craig. 1981. A major ^{3}He source on the East Pacific Rise, Science, 214: 13-18.

Lupton, J. E. 1983. Terrestrial inert gases: isotopic tracer studies and clues to primordial components in the mantle, Ann. Rev. Earth. Planet. Sci., 11: 371-414.

Lupton, J. G. and H. Craig. 1975 Excess ^{3}He in oceanic basalts: evidence for terrestrial primordial helium, Earth. Planet. Sci. Lett., 26: 133-.

Maggi F. and Riley, W.J. 2010. Mathematical treatment of isotopologue and isotopomer speciation and fractionation in biochemical kinetics. Geochimica et Cosmochimica Acta, 74(6): 1823–1835.

Mahon, K.I. 1996. The new 'York' regression: application of an improved statistical method to geochemistry. International Geology Review 38(4): 293–303.

Mark, D. F., Stuart, F. M. and de Podesta, M. 2011. New high-precision measurements of the isotopic composition of atmospheric argon. Geochimica et Cosmochimica Acta, 75: 7494–7501.

Marshall, B. D. and D. J. DePaolo, Initial Ca isotope variations in igneous rocks: implications for petrogenetic models and the composition of the lower crust, EOS, 68; 465, 1987.

Martin, C. E. 1991. Osmium isotopic characteristics of mantle-derived rocks, Geochim. Cosmochim.Acta, 55, 1421-1434.

Mattey, D. P. 1987. Carbon isotopes in the mantle. Terra Cognita. 7: 31-38.

Mattey, D., D. Lowry and C. Macpherson. 1994. Oxygen isotope composition of mantle peridotite. Earth Planet. Sci. Lett. 128: 231-241.

Mattinson, J. 2005. Zircon U–Pb chemical abrasion ("CA-TIMS") method: combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages. Chemical Geology, 220(1-2), 47–66.

Mattinson, J. M. 2010. Analysis of the relative decay constants of ^{235}U and ^{238}U by multi-step CA-TIMS measurements of closed-system natural zircon samples. Chemical Geology, 275: 186–198.

McArthur, J. M., Howarth, R. J. and Bailey, T. R. 2001. Strontium isotope stratigraphy: LOWESS Version 3: Best fit to the marine Sr–isotope curve for 0–509Ma and accompanying look–table for deriving numerical age. The Journal of Geology, 109: 155–170,

McDougall, I. and Harrison, T. M. 1999. Geochronology and Thermochronology by the ^{40}Ar/39Ar Method. 2nd edn. New York: Oxford University Press, 269 p.

McLean, N. Condon, D.J., Schoene, B., and Bowring, S.A. 2015 Evaluating Uncertainties in the Calibration of Isotopic Reference Materials and Multi-Element Isotopic Tracers (EARTHTIME Tracer Calibration Part II). Geochimica et Cosmochimica Acta. Volume 164, 1, 481-501.

McLean, N. M., J. F. Bowring, and S. A. Bowring 2011, An algorithm for U-Pb isotope dilution data reduction and uncertainty propagation, Geochem. Geophys. Geosyst., 12, Q0AA18,

Merrihue, C. and Turner, G. 1966. Potassium-argon dating by activation with fast neutrons. Journal of Geophysical Research, 71: 2852–2857.

Milankovitch, M. 1938. Astronomische mittel zur erforschung der erdgeschlichtlichen klimate,Handbuch der Geophysik, 9: 593-698.

Min, K. W., Mundil, R., Renne, P.R., and Ludwig, K.R., 2000. A test for systematic errors in ^{40}Ar/^{39}Ar geochronology through comparison with U/Pb analysis of a 1.1-Ga rhyolite. Geochimica et Cosmochimica Acta, v. 64, i. 1, p. 73-98.

mineralization in central Victoria, Australia, Economic Geology, 6: 1455–1459.

Morgan, L.E., Postma, O., Kuiper, K.F., Mark, D.F., van der Plas, W., Davidson, S., Perkin, M., Villa, I.M., Wijbrans, J.R., 2011. A metrological approach to measuring ^{40}Ar* concentrations in K-Ar and ^{40}Ar/^{39}Ar mineral standards. Geochemistry, Geophysics, Geosystems, v. 12, i. 10.

Muehlenbachs, K. and G. Byerly. 1982. 18O enrichment of silicic magmas caused by crystal fractionation at the Galapagos Spreading Center, Contrib. Mineral. Petrol., 79, 76-79.

Mulcahy, S. R., King, R. L. and Vervoort, J. D. 2009. Lawsonite Lu-Hf geochronology: A new geochronometer for subduction zone processes. Geology, 37: 987–990.

Nebel, O., Scherer, E. E. and Mezger, K. 2011. Evaluation of the ^{87}Rb decay constant by age comparison against the U–Pb system. Earth and Planetary Science Letters, 301: 1–8.

Nesheim, T. O., Vervoort, J. D., McClelland, W. C., Gilotti, J. A. and Lang, H. M. 2012. Mesoproterozoic syntectonic garnet within Belt Supergroup metamorphic tectonites: Evidence of Grenville-age metamorphism and deformation along northwest Laurentia. Lithos, 134-135: 91–107.

Niespolo, E.M., Rutte, D., Deino, A.L., and Renne, P.R., 2017. Intercalibration and age of the Alder Creek sanidine 40Ar/39Ar standard. Quaternary Geochronology, v. 39, p. 205-213.

Nyquist, L. E., Bogard, D. D., Wiesmann, H., Bansal., B. M., Shih, C.-Y. and Morris, R. M. 1990. Age of a eucrite clase from the Bholghati howardite. Geochimica et Cosmochimica Acta. 54: 2195–2206.

Nyquist, L. E., D. D. Bogard, H. Wiesmann, B. M. Bansal., C.-Y. Shih and R. M. Morris. 1990. Age of a eucrite clase from the Bholghati howardite. Geochim. Cosmochim. Acta. 54: 2195-2206.

O'Neil, J., Carlson, R. L., Francis D. and Stevenson, R. K. 2008. Neodymium-142 evidence for Hadean mafic crust, Science, 321: 1828–1831.

Ohmoto, H. and R. O. Rye, Isotopes of Sulfur and Carbon, in Geochemistry of Hydrothermal Ore Deposits, edited by H. Barnes, p. John Wiley and Sons, New York, 1979.

Ohmoto, H., Stable isotope geochemistry of ore deposits, in Stable Isotopes in High Temperature Geological Processes, Reviews in Mineralogy 16, edited by J. W. Valley, H. P. Taylor and J. R.O'Neil, p. 491-560. Washington: Mineral. Soc. Am.

O'Leary, M. H. 1981. Carbon isotope fractionation in plants, Phytochemistry, 20, 553-567.

O'Neil, J. R. 1986. Theoretical and experimental aspects of isotopic fractionation, in Stable Isotopes In Hiigh Temperature Geologic Processes, Reviews in Mineralogy Volume 16, J. W. Valley, H. P. Taylor and J. R. O'Neil, eds., Mineralogical Society of America, Washington, pp. 1-40, 1986.

Ozima, M. and K. Zahnle. 1993. Mantle degassing and atmospheric evolution: noble gas view, Geochem.J., 27, 185-200.

Palmer, M. R. 1991. Boron-isotope systematics of Halmahera arc (Indonesia) lavas: evidence for involvement of the subducted slab. Geology. 19: 215-217.

Palmer, M., M. Spivack and J. M. Edmond. 1987. Temperature and pH controls over isotopic fractionation during adsorption of boron on marine clay. Geochim. Cosmochim. Acta. 51: 2319-2323.

Park, R. and S. Epstein. 1960. Carbon isotope fractionation during photosynthesis, Geochim. Cosmochim.Acta, 21, 110-126.

Patchett, P. J. 1983. Importance of the Lu-Hf isotopic system in studies of planetary chronology and chemical evolution, Geochim. Cosmochim. Acta, 47: 81-91.

Patchett, P. J., Vervoort, J. D., Söderlund, U. and Salters, V. J. M. 2004. Lu-Hf and Sm-Nd isotopic systematics in chondrites and their constraints on the Lu-Hf properties of the Earth. Earth and Planetary Science Letters, 222: 29–41.

Patchett, P. J., W. M. White, H. Feldmann, S. Kielinczuk and A. W. Hofmann. 1984. Hafnium/rare earth element fractionation in the sedimentary system and crustal recycling into the Earth's mantle.Earth. Planet. Sci. Lett. 69: 365-378.

Patterson, C. 1956. Age of meteorites and the earth. Geochimica et Cosmochimica Acta 10(4): 230–237

Paul, M., A. Kaufman, M. Magaritz, D. Fink, W. Henning, et al. 1986. A new ^{36}Cl hydrological model and ^{36}Cl systematics in the Jordan River/Dead Sea system, Nature, 29, 511-515.

Peucker-Ehrenbrink, B., G. Ravissa and A. W. Hoffmann. 1995. The marine ^{187}Os/ ^{186}Os record of the past 80 million years. Earth Planet. Sci. Lett. 130: 155-167.

Phillips, D., Matchan, E.L., 2013. Ultra-high precision ^{40}Ar/^{39}Ar ages for Fish Canyon Tuff and Alder Creek Rhyolite sanidine: New dating standards required? Geochimica et Cosmochimica Acta 121, 229-239.

Porcelli, D.; C. J. Ballentine & R. Wieler. 2002. Noble Gases in Geochemistry and Cosmochemistry. Reviews in Mineralogy and Geochemistry, Vol. 47. 867 pp.

Poreda, R. J. and K. A. Farley, Rare gases in Samoan xenoliths. 1992. Earth Planet. Sci. Lett., 113,129-144.

Powell, R., Hergt, J. and Woodhead, J. 2002. Improving isochron calculations with robust statistics and the bootstrap. Chemical Geology 3–4: 191–204.

Quade, J., T. E. Cerling and J. R. Bowman. 1989. Development of Asian monsoon revealed by marked ecological shift during the latest Miocene in northern Pakistan, Nature, 342, 163-166.

Ravizza, G. and Turekian, K.K. 1989. Application of the ^{187}Re–^{187}Os system to black shale geochronometry. Geochimica et Cosmochimica Acta 53(12): 3257–3262.

Reisberg, L., A. Zindler, F. Marcantonio, W. M. White, D. Wyman, and B. Weaver. 1993. Os isotope systematics in ocean island basalts. Earth Planet. Sci. Lett. 120: 149-167.

Renne, P. R., Cassata, W.S., and Morgan, L.E., 2009. The isotopic composition of atmospheric argon and ^{40}Ar/^{39}Ar geochronology: Time for a change? Quaternary Geochronology, v. 4, i.4, p. 288-298.

Renne, P. R., et al., 2009. Data reporting norms for 40Ar/39Ar geochronology. Quaternary Geochronology, v. 4, i. 5, p. 346-352.

Renne, P. R., Mundil, R., Balco, G., Min, K. and Ludwig, K. R. 2010. Joint determination of ^{40}K decay constants and ^{40}Ar*/^{40}K for the Fish Canyon sanidine standard, and improved accuracy for ^{40}Ar/^{39}Ar geochronology, Geochimica et Cosmochimica Acta, 74: 5349–5367.

Renne, P.R., Balco, G., Ludwig, K.R., Mundil, R., Min, K., 2011. Response to the comment by W.H. Schwarz et al. on “Joint determination of ^{40}K decay constants and ^{40}Ar*/^{40}K for the Fish Canyon sanidine standard, and improved accuracy for ^{40}Ar/^{39}Ar geochronology” by PR Renne et al. (2010). Geochimica et Cosmochimica Acta 75, 5097-5100.

Richardson, S. H., Shirey, S. B., Harris, J.W. and Carlson, R. L. 2001. Archean subduction recorded by Re-Os isotopes in eclogitic sulfide inclusions in Kimberley diamonds, Earth and Planetary Science Letters, 191: 257–266.

Richet, P., Y. Bottinga and M. Javoy. 1977. A review of hydrogen, carbon, nitrogen, oxygen,sulphur, and chlorine stable isotope fractionation among gaseous molecules, Ann. Rev. Earth Planet. Sci. Lett., 5, 65-110.

Rivera, T.A., Storey, M., Zeeden, C., Hilgen, F.J., Kuiper, K., 2011. A refined astronomically calibrated 40Ar/39Ar age for Fish Canyon sanidine. Earth and Planetary Science Letters 311, 420-426.

Rotenberg, E., Davis, D. W. and Amelin, Y. 2005. Determination of the ^{87}Rb decay constant by ^{87}Sr accumulation, Geochimica et Cosmochimica Acta, 69 supplement: A326.

Sakai, H., D. J. Des Marais, A. Ueda and J. G. Moore. 1984. Concentrations and isotope ratios ofcarbon, nitrogen, and sulfur in ocean-floor basalts, Geochim. Cosmochim. Acta, 48, 2433-2442,1984.

Sanyal, A., N. G. Hemming, G. N. Hanson and W. S. Broecker. 1995. Evidence for a higher pH in the glacial ocean from boron isotopes in foraminifera. Nature. 373: 234-236.

Sarda, P., T. Staudacher and C. J. Allègre. 1988. Neon isotopes in submarine basalts, Earth Planet. Sci. Lett., 91, 73-88.

Savin, S. M. and S. Epstein, The oxygen and hydrogen isotope geochemistry of clay minerals, Geochim.Cosmochim. Acta, 34, 25-42, 1970.

Schaltegger, U., Schmidtt, A.K., and Horstwood, M.S.A. 2016 U–Th–Pb zircon geochronology by ID-TIMS, SIMS, and laser ablation ICP-MS: Recipes, interpretations, and opportunities. Chemical Geology.

Scherer, E., Munker, C. and Mezger, K. 2001. Calibration of the Lutetium-Hafnium Clock, Science, 293: 683–686.

Schmitz, M. D., and B. Schoene, 2007, Derivation of isotope ratios, errors, and error correlations for U-Pb geochronology using ^{205}Pb-^{235}U-

(^{233}U)-spiked isotope dilution thermal ionization mass spectrometric data, Geochem. Geophys. Geosyst., 8, Q08006,

Schmitz, M.D. and Kuiper, K.F. Elements 2013 High-precision geochronology. Elements. Elements, v. 9, i. 1, p. 25-30.

Schmitz, M.D. and Kuiper, K.F., 2013. High-precision geochronology. Elements. Elements, v. 9, i. 1, p. 25-30.

Schmitz, M.D., 2012. Radiogenic isotope geochronology. Geologic Time Scale, 115–126

Schoene, B., 2014, 4.10 – U–Th–Pb Geochronology, in Holland, H. D., and Turekian, K. K., eds., Treatise on Geochemistry (Second Edition): Oxford, Elsevier, p. 341-378

Schoene, B., Condon, D.J., Morgan, L., and McLean, N., 2013. Precision and Accuracy in Geochronology. Elements, v. 9, i. 1, p. 19-24

Schoeninger, M. J. and M. J. DeNiro. 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals, Geochim. Cosmochim. Acta, 48, 625-639.

Schwarcz, H. P., E. K. Agyei and C. C. McMullen. 1969. Boron isotopic fractionation during clay adsorption from sea-water. Earth Planet. Sci. Lett. 6: 1-5.

Selby, D. and Creaser, R. A. 2005. Direct radiometric dating of hydrocarbon deposits using rhenium-osmium isotopes. Science, 308: 1293–1295.

Selby, D. and Creaser, R.A. 2003. Re–Os geochronology of organic rich sediments: an evaluation of organic matter analysis methods. Chemical Geology 200(3–4): 225–240.

Selby, D., Creaser, R. A. and Fowler, M. G. 2007. Re-Os elemental and isotopic systematics in crude oils. Geochimica Cosmochimica Acta, 71: 378–386.

Selby, D., Creaser, R.A. and Fowler, M.G. 2007. Re–Os elemental and isotopic systematics in crude oils. Geochimica et Cosmochimica Acta 71(2): 378–386.

Shackleton, N. J. and N. D. Opdyke. 1973. Oxygen isotope and paleomagnetic stratigraphy of anequatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10 5 and 10 6 year time scale, Quat. Res., 3, 39-55.

Sharp, Z. 2017. Principles of stable isotope geochemistry. Prentice-Hall (original), 385 pp.

Sheppard, S. M. F. and C. Harris. 1985. Hydrogen and oxygen isotope geochemistry of Ascension Island lavas and granites: variation with fractional crystallization and interaction with seawater, Contrib. Mineral. Petrol., 91, 74-81.

Sheppard, S. M. F. and S. Epstein. 1970. D/H and ^{18}O/^{16}O ratios of minerals of possible mantle or lower crustal origin. Earth Planet. Sci. Lett. 9: 232-239.

Sheppard, S. M. F., R. L. Nielsen and H. P. Taylor. 1969. Oxygen and hydrogen isotope ratios of clay minerals from porphyry copper deposits. Econ. Geol. 64: 755-777.

Shirey, S. B., Richardson, S. H. and Harris, J.W. 2004. Integrated models of diamond formation and craton evolution, Lithos, 77: 923–944.

Simon, J.I., Renne, P.R., Mundil, R., 2008. Implications of pre-eruptive magmatic histories of zircons for U-Pb geochronology of silicic extrusions. Earth and Planetary Science Letters 266, 182-194.

Sircombe, K.N. and Hazelton, M.L. 2004. Comparison of detrital age data by kernel functional estimation. Sedimentary Geology 171(1–4): 91–111.

Sircombe, K.N. and Hazelton, M.L. 2004. Comparison of detrital age data by kernel functional estimation. Sedimentary Geology 171(1–4): 91–111.

Snow, J. E., and Schmidt, G. 1998. Constraints on Earth accretion deduced from noble metals in the oceanic mantle, Nature, 391: 166–169.

Söderlund, U., Patchett, P. J., Vervoort, J. D. and Isachsen, C. E. 2004. The ^{176}Lu decay constant determined by Lu–Hf and U–Pb isotope systematics of Precambrian mafic intrusions. Earth and Planetary Science Letters, 219: 311–324.

Spivack, A. and J. M. Edmond. 1987. Boron isotope exchange between seawater and the oceanic crust. Geochim. Cosmochim. Acta. 51: 1033-1044.

Spivack, A. J., C.-F. You and H. J. Smith. 1993. Foraminiferal boron isotope ratios as a proxy for surface ocean pH over the past 21 Myr. Nature. 363: 149-151.

Stacey, J.D. and Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by a two stage model. Earth and Planetary Science Letters 26(2): 207–221.

Stein, H.J., Markey, R.J., Morgan, J.W., Hannah, J.L. and Schersten, A. 2001. The remarkable Re–Os chronometer in molybdenite: how and why it works. Terra Nova 13: 479–486.

Stracke, A., Hofmann, A.W. and Hart, S.R. 2005. FOZO, HIMU, and the rest of the mantle zoo. Geochemistry, Geophysics, Geosystems 6(5): 1–20.

Stumpf, R., Frank, M., Schönfeld, J. and Haley, B. A. 2010. Late Quaternary variability of Mediterranean Outflow Water from radiogenic Nd and Pb isotopes. Quaternary Science Reviews, 29: 2462–2472,

Sun, S.S. and McDonough, W.F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and

processes. Geological Society of London, Special Publications 42: 313–345.

Suzuki, K. and Kato, T., 2008. CHIME dating of monazite, xenotime, zircon and polycrase: protocol, pitfalls and chemical criterion of possibly discordant age data. Gondwana Research, 14: 569–586.

Tagami, T. and O'Sullivan, P. B. 2005. Fundamentals of Fission-Track Thermochronology. Reviews in Mineralogy andGeochemistry, 58: 19–47.

Tatsumoto, M., Unruh, D. M. and Patchett, P. 1981. U-Pb and Lu-Hf systematics of Antarctic meteorites, Mem. Nat. Inst. Polar. Res. Tokyo, Spec. Issue, 20: 237–249.

Taylor, H. P. 1974. The application of oxygen and hydrogen studies to problems of hydrothermal alteration and ore deposition, Econ. Geol., 69, 843-883.

Taylor, H. P. 1980. The effects of assimilation of country rocks by magmas on $^{18}O/^{16}O$ and $^{87}Sr/^{86}Sr$ systematics in igneous rocks., Earth Planet. Sci. Lett., 47, 243-254.

Taylor, H. P. and S. M. F. Sheppard, Igneous rocks: I. Processes of isotopic fractionation and isotope systematics, in Stable Isotopes in High Temperature Geological Processes, edited by J. W.Valley, H. P. Taylor and J. R. O'Neil, p. 227-271. Washington: Mineral. Soc. Am.

Tera, F. and Wasserburg, G.J. 1972. U–Th–Pb systematics in three Apollo 14 basalts and the problem of initial Pb in lunar rocks. Earth and Planetary Science Letters 14: 281–304.

Tera, F., L. Brown, J. Morris, I. S. Sacks, J. Klein, R. Klein and R. Middleton. 1986. sediment incorporation in island-arc magmas: inferences from 10Be, Geochim. Cosmochim. Acta, 50: 535-550.

Tetley, N. W. 1978. Geochronology by the $^{40}Ar/^{39}Ar$ Method Using the HIFAR Reactor. PhD dissertation, Australian National University, Canberra.

Thiemens M.H., Chakraborty, S. and Dominguez, G. 2012. The physical chemistry of mass-independent isotope effects and their observation in nature. Annual Review of Physical Chemistry 63: 155–177.

Thrane, K., Connelly, J. N., Bizzarro, M., Meyer, B. S. and The, L.-S. 2010. Origin of excess ^{176}Hf in meteorites. The Astrophysical Journal, 717: 861–867.

Touboul, M., Kleine, T., Bourdon, B., Palme, H. and Wieler, R. 2007. Late formation and prolonged differentiation of the Moon inferred from W isotopes in lunar metals. Nature, 450: 1206–1209.

Touboul, M., Kleine, T., Bourdon, B., Palme, H. and Wieler, R. 2009. Tungsten isotopes in ferroan anorthosites: Implications for the age of the Moon and lifetime of its magma ocean. Icarus, 199: 245–249.

Touboul, M., Puchtel, I. S. and Walker, R. J. 2012. ^{182}W evidence for long-term preservation of early mantle differentiation products. Science, 335: 1065–1069.

Trinquier, A., Birck, J. L., Allègre, C. J., Göpel, C. and Ulfbeck, D. 2008. $^{53}Mn–Cr$ systematics of the early Solar System revisited. Geochimica et Cosmochimica Acta, 72: 5146–5163.

Upadhyay, D., Scherer, E. E. and Mezger, K. 2009. ^{142}Nd evidence for an enriched Hadean reservoir in cratonic roots. Nature, 459: 1118–1121.

Urey, H. 1947. The thermodynamic properties of isotopic substances, J. Chem. Soc. (London),1947:562-581.

Valley, J. W., H. P. Taylor and J. R. O'Neil (editors). 1986. Stable Isotopes in High Temperature Applications, Reviews in Mineralogy Volume 16. Washington: Mineral. Soc. Am.

Vengosh, A., Y. Kolodny, A. Starinsky, A. Chivas and M. McCulloch. 1991. Coprecipitation and isotopic fractionation of boron in modern biogenic carbonates. Geochim. Cosmochim. Acta. 55:2901-2910.

Vermeesch, P. 2004. How many grains are needed for a provenance study? Earth and Planetary Science Letters 224(3–4): 441–451.

Vermeesch, P. 2012. On the visualisation of detrital age distributions. Chemical Geology. 312–313: 190–194.

Vermeesch, P., 2015. Revised error propagation of $^{40}Ar/^{39}Ar$ data, including covariances. Geochimica et Cosmochimica Acta, v. 171, p. 325-337.

Vervoort, J. D. and Blichert-Toft, J. 1999. Evolution of the depleted mantle; Hf isotope evidence from juvenile rocks through time. Geochimica et Cosmochimica Acta, 63: 533–556.

Vervoort, J. D., Plank, T. and Prytulak, J. 2011. The Hf–Nd isotopic composition of marine sediments. Geochimica et Cosmochimica Acta, 75: 5903–5926.

Villeneuve, J., Chaussidon, M. and Libourel, G. 2009. Homogeneous distribution of 26Al in the Solar System from the Mg isotopic composition of chondrules. Science, 325: 985–988.

Volpe, A. M. and P. E. Hammond. 1991. ^{238}U -^{230}Th-^{226}Ra disequilibria in young Mount St. Helens rocks: time constraint for magma formation and crystallization, Earth Planet. Sci. Lett., 107, 475-486.

Wadhwa, M., Amelin, Y., Bogdanovski, O., Shukolyukov, A., Lugmair, G. W. and Janney, P. 2009. Ancient relative and absolute ages for a

basaltic meteorite: Implications for timescales of planetesimal accretion and differentiation. Geochimica et Cosmochimica Acta, 73: 5189–5201.

Walker, R. J., Carlson, R. W., Shirey, S. B. and Boyd, F. R. 1989. Os, Sr, Nd, and Pb isotope systematics of southern African peridotite xenoliths: implications for the chemical evolution of the subcontinental mantle. Geochimica et Cosmochimica Acta, 53: 1583–1595.

Walker, R. J., Morgan, J. W., Naldrett, A. J., Li, C. and Fassett, J. D. 1991. Re-Os isotope systematics of Ni-Cu sulfide ores, Sudbury igneous complex, evidence for a major crustal component. Earth and Planetary Science Letters, 105: 416–429.

Walker, R. J., R. W. Carlson, S. B. Shirey and F. R. Boyd. 1989. Os, Sr, Nd, and Pb isotope systematics of southern African peridotite xenoliths: implications for the chemical evolution of the subcontinental mantle. Geochim. Cosmochim. Acta. 53: 1583-1595.

Walker, R. J., Shirey, S. B. and Stecher, O. 1988. Comparative Re-Os, Sm-Nd and Rb-Sr isotope and trace element systematics for Archean komatiite flows from Munro Township, Abitibi Belt, Ontario. Earth and Planetary Science Letters 87: 1–12.

Wang, Y., C. E. Cerling and B. J. McFadden. 1994. Fossil horse teeth and carbon isotopes: new evidence for Cenozoic dietary, habitat, and ecosystem changes in North America, Paleogeogr.,Paleoclim., Paleoecol. in press.

Wendt, I. and Carl, C. 1991. The statistical distribution of the mean squared weighted deviation. Chemical Geology: Isotope Geoscience Section, 86: 275–285.

Wetherill, G.W. 1956. Discordant uranium–lead ages. Transactions of the American Geophysical Union 37: 320–326.

Whitby, J. A., Gilmour, J. D., Turner, G., Prinz, M. and Ash, R. D. 2002. Iodine-Xenon dating of chondrules from the ingzhen and Kota Kota enstatite chondrites. Geochimica et Cosmochimica Acta, 66: 347–359.

Whitby, J., Burgess, R., Turner, G., Gilmour, J. and Bridges, J. 2000. Extinct ^{129}I in halite from a primitive meteorite: evidence for evaporite formation in the early Solar System. Science, 288: 1819–1821,

White, W. M., P. J. Patchett and D. BenOthman. 1986. Hf isotope ratios of marine sediments and Mn nodules: evidence for a mantle source of Hf in seawater. Earth Planet. Sci. Lett. 79: 46-54.

White, W.M. 2015, Isotope Geochemistry. Wiley, pp. 426.

White,W. M., Patchett, P. J. and Ben Othman, D. 1986. Hf isotope ratios of marine sediments and Mn nodules: evidence for a mantle source of Hf in seawater. Earth and Planetary Science Letters, 79: 46–54,

Woodhead, J., Hergt, J., Shelley, M., Eggins, S. and Kemp, R. 2004. Zircon Hf-isotope analysis with an excimer laser, depth profiling, ablation of complex geometries, and concomitant age estimation. Chemical Geology 209(1–2): 121–135.

Wotzlaw, J.-F., Husing, S.K., Hilgen, F.J., Schaltegger, U., 2014. High-precision zircon U-Pb geochronology of astronomically dated volcanic ash beds from the Mediterranean Miocene. Earth and Planetary Science Letters 407, 19-34.

York, D. 1969. Least squares fitting of a straight line with correlated errors. Earth and Planetary Science Letters 5: 320–324.

You, C.-F. 1994. Comment on “Boron content and isotopic composition of oceanic basalts:geochemical and cosmochemical implications” by M. Chaussidon and A. Jambon. Earth Planet.Sci. Lett. 128: 727-730.

Zentilli, M. and Reynolds, P. H. (eds) 1992. Short Course Handbook on Low Temperature Thermochronology.Nepean,Ontario: Mineralogical Society of Canada.

Zindler, A. and Hart, S. 1986. Chemical geodynamics. Annual Reviews in Earth and Planetary Sciences 14: 493–571

Zindler, A. and S. R. Hart. 1986. Helium: problematic primordial signals, Earth. Planet Sci. Lett., 79: 1-8.

Dr. Rubén López
Director
Dpto. Ciencias Geológicas
FCEN - UBA

Dr. Héctor A. Ostera
Profesor Asociado Regular
Cátedra de Geología Isotópica