

## CURRICULUM VITAE

9/2/2022

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### EDUCATION:

1973 : B.A. with honors - Harvard University -  
History of Science and Geology  
1977 : M.S. - SUNY, Stony Brook, New York  
1980 : Ph.D. - SUNY, Stony Brook

### EMPLOYMENT:

1981 - 1986 : Assistant Professor, Lamont-Doherty Earth Obs., of  
Columbia University, Palisades, New York 10964  
1986 - 1988 : Associate Professor, Lamont-Doherty Earth Obs.  
1988 - 2002 : Professor, Lamont-Doherty Geol. Obs.  
1989 - 2002 : Arthur D. Storke Memorial Professor, Lamont-Doherty  
1989 - 1990 : Visiting Scientist, Institut de Physique du Globe, Paris  
2002 - 2003 : Visiting Scientist, Institut de Physique du Globe, Paris  
2002 - 2006 : Professor of Geochemistry, Harvard University  
2006- : Higgins Professor of Geochemistry and Director of the Harvard  
Geological and Mineralogical Museum

### FELLOWSHIPS AND AWARDS:

1973 - 1974 : Henry Russell Shaw traveling fellowship from  
Harvard University  
1980 - 1981 : Post-doctoral fellowship from Lamont-Doherty  
1983 - 1985 : Alfred Sloan Research Fellow  
1993 : Fellow, American Geophysical Union  
1996 : N. L. Bowen Award, American Geophysical Union  
1997 : Fellow, American Academy of Arts and Sciences  
1998 : Daly Lecturer, American Geophysical Union  
1998 : Fellow, Geochemical Society and European Geochem. Soc.  
2003 : Arthur Holmes Medal, European Union of Geosciences  
2006 : National Academy of Sciences  
2010 : Urey Medal, European Association of Geochemistry  
2011 : Astor Lectureship, Oxford University  
2011-2012 : Leverhulme Fellowship, Oxford University  
2015 : Shen-Su Sun Lectureship  
2015 : Kuang-chi Tu Lectureship, Guangzhou University  
2015 : Distinguished visiting scholar, Zhejiang University  
2016 : Einstein lectureship, Chinese Academy of Sciences  
2017 : Global Lecture Series, Zheljiang University  
2020 : Chinese Academy of Sciences Presidential Scholar

## PROFESSIONAL ACTIVITIES (selection):

1986-1987	:	Chairman Consortium on Scientific Ocean Drilling working group on mantle/crust interaction
1987-1991	:	RIDGE steering committee
1987 - 1998	:	Editor, <i>Earth and Planetary Science Letters</i>
1988 - 2002	:	Editorial Board, <i>Chemical Geology</i>
1988 - 1989	:	Chairman, RIDGE Global Structure and Fluxes Working Group
1989 - 1994	:	Chairman, Coordinating Committee, Project FARA (French-American-Ridge Atlantic)
1990	:	Chair, Director Search Committee, Lamont-Doherty
1990 - 1994	:	NSF Advisory Committee on Ocean Sciences
1991 - 1993	:	RIDGE Steering Committee
1991 - 1996	:	InterRIDGE Steering Committee
1993 - 1996	:	Chairman, InterRidge Global Studies Working Group
1995 - 1998	:	AGU Fellows Committee
1995 -	:	Geochemical Society Goldschmidt Committee
1995 - 1996	:	National Science Foundation, Ocean Sciences Review Board
1996-1997	:	NSF, Future of Marine Geosciences Steering Committee
1995-1997	:	NSF Ocean Sciences Panel
1998	:	Co-founder, <i>Geochemistry, Geophysics, Geosystems</i>
1998 - 2000	:	Chair, Executive Committee G <sup>3</sup> – <i>Geochemistry, Geophysics, Geosystems</i>
1998 - 2000	:	Geochemical Society Fellows Committee
1998 - 2000	:	Committee on Instruction, Columbia University
1998 -2002	:	Principal Investigator and Founder, PetDB (Petrological Database of the Sea Floor, the first geochemical database)
1999 - 2001	:	Administrative Committee LDEO
1999 - 2001	:	Chair, Earth Sciences Leadership Search Committee, LDEO
2002 - 005	:	Ridge 2000 Steering Committee
2000- 2002	:	AGU Nominations Committee
1999- 2001	:	Chair, Earth Sciences Leadership Search Committee . LDEO
2006 -	:	Director of the Geological and Mineralogical Museum, Harvard University
2006-2020_	:	Executive committee, Earth and Planetary Sciences, Harvard
2008 - 2011	:	Program Committee, American Association for the Advancement of Science
2011	:	NSF advisory committee on future of the ocean drilling program
2011-	:	Executive committee, Harvard Museums of Science and Culture
2011-2017	:	NSF Ocean Sciences Review Panels
2015	:	Woods Hole Oceanographic Institution Visiting Committee

## SEAGOING EXPERIENCE:

1984	R/V Kana Keoki	Izu volcanic arc and back-arc rifts (Petrologist)
1985	R/V New Horizon	East Pacific Rise : 6°-13°N (Co-Chief Scientist - CHEPR)
1985	R/V Knorr	Mid-Atlantic Ridge : Kane Fracture Zone (Chief for petrology program)
1987	R/V Oceanus	Mid-Atlantic Ridge : 26°-32°N (Chief for petrology program)
1987	R/V Atlantis II/Alvin	Bonin back-arc rifts (Petrologist)
1989	R/V T. Washington E.	Pacific Rise (Co-Chief Scientist - VENTURE)
1991	R/V Atalante	Mid-Atlantic Ridge (Petrologist - Project SIGMA)
1992	R/V Atlantis II	Mid-Atlantic Ridge, 32°41°N (Chief Scientist - FAZAR)

1993	R/V Atlantis II/Alvin	Lucky Strike Hydrothermal Site (Chief Scientist)
1993	R/V Hakuko-Maru	Indian Ocean Triple Junction (Petrologist)
1997	R/V Melville	East Pacific Rise (Chief Scientist - OROZCO)
2001	USCGC Healy	Gakkel Ridge, Arctic Ocean, Principal Investigator
2004	R/V Kilo Moana	Lau Basin, South Pacific, Chief Scientist
2011	R/V Araon	Australian-Antarctic Ridge, petrologist
2012	R/V Knorr	Mid-Atlantic Ridge, Chief Scientist
2014	R/V Atlantis	Juan de Fuca Ridge, Chief Scientist

## NOTABLE SERVICE

Was the Principal Investigator for the founding of PetDB, the petrological data base of the sea floor which with GEOROC was the first major geochemical database, widely used by hundreds of investigators.

Founded (with five others) the journal *Geochemistry, Geophysics, Geosystems*, which we turned over to AGU in order to provide a more secure journal platform.

Developed the “wax coring” method of basalt sampling at ocean ridges, which increased sampling efficiency by a factor of three and has been adopted internationally as a standard complement to dredging and submersible sampling.

Rewrote and expanded the original book by Wally Broecker, *How to Build a Habitable Planet*, which won honorable mention as one of the best earth science books of 2012, and is widely used in introductory Earth science courses internationally.

## PUBLICATION LIST (No abstracts or grey literature):

**BOOK:** Langmuir, C. H., & Broecker, W. (2012). *How to Build a Habitable Planet, 2<sup>nd</sup> Edition*, Princeton University press.

## PAPERS:

- Langmuir, C., Bender, J., Bence, A., Hanson, G. and Taylor, S. (1977). Petrogenesis of basalts from the FAMOUS area: Mid-Atlantic Ridge. *Earth Planet. Sci. Lett.*, 36, 133-156.
- Langmuir, C., Vocke, R., Hanson, G. and Hart, S. (1978). A general mixing equation with applications to Icelandic basalts. *Earth Planet. Sci. Lett.*, 37, 380-392.
- Hanson, G. and Langmuir, C. (1978). Modeling of major elements in mantle-melt systems using trace element approaches. *Geochim. Cosmochim. Acta*, 42, 725-742.
- Rice, S., Langmuir, C., Bender, J., Bence, A., Taylor, S. (1978). “Basalts from DSDP Sites 417 A, D: Fractionated melts of a light rare earth depleted source”, in *Initial Reports of the Deep Sea Drilling Project*, 51, Washington, D.C. (U.S. Government Printing office).
- Langmuir, C. and Hanson, G. (1980). An evaluation of major element heterogeneity in the mantle sources of basalts. *Philos. Trans. of the Royal Society London*, A297, 383-407.
- Langmuir, C. (1980). *A major and trace element approach to basalts*, Ph.D. Thesis, SUNY, Stony Brook, pp. 300.
- Langmuir, C. and Hanson, G. (1981). “Calculating mineral-melt equilibria with stoichiometry, mass balance, and single-component distribution coefficients”, in *Thermodynamics of Minerals and Melts, Advances in Physical Geochemistry, Vol. 1*, R. C. Newton, A. Navrotsky, and B.J. Wood (eds.), pp. 247-271, Springer-Verlag, New York.
- Nabelek, P., Langmuir, C., Bence, A. (1982) "The polybaric history of FAMOUS basalt 527-1-1: Evidence from trace elements in olivine", in *Microbeam Analysis*, Roy H. Geiss (ed.), 151-154.
- Bender, J., Langmuir, C., Hanson, G. (1984). Petrogenesis of basalt glasses from the Tamayo region. *J. Petrol.*, 25, 213-254.
- Langmuir, C. and Bender, J. (1984). Geochemical variations around transform faults: Observations and implications. *Earth. Planet. Sci. Lett.*, 69, 107-127.
- Perfit, M. and Langmuir C. (1984). "Geochemistry of Volcanic Rocks from the Woodlark Basin: Addressing the questions of ridge subduction and a reversal in the polarity of subduction", in

- Seafloor Spreading Ridge Subduction, Volcanism and Sedimentation in the Offshore Woodlark-Solomons Regions*, B. Taylor and N. Exon (eds.), CCOP/SOPAC Technical Rept., 34, 387-467.
- Johnson, R., Jaques, A., Langmuir, C., et al. (1984). "Igneous petrology and geochemistry of the New Georgia Group forearc area: The magmatic effects of ridge subduction" in *Seafloor Spreading Ridge Subduction, Volcanism and Sedimentation in the Offshore Woodlark-Solomons Regions*, B. Taylor and N. Exon (eds.), CCOP/SOPAC Technical Rept., 34, 77-185.
- Nabelek, P. and Langmuir, C. (1985). The significance of unusual zoning in olivines from FAMOUS area basalt 527-1-1. *Contrib. Mineral. Petrol.*, 93, 1-8.
- Langmuir, C., Bender, J., Batiza, R. (1986). Petrologic and tectonic segmentation of the East Pacific Rise from 6°-14°N. *Nature*, 332, 422-429.
- Christie, D., Carmichael, I., Langmuir, C. (1986). Ferric/Ferrous ratios and oxygen fugacities of mid-ocean ridge basalt glasses. *Earth Planet. Sci. Lett.*, 79, 397-411.
- Shirey, S., Bender, J., Langmuir, C. (1987). Three-component isotopic heterogeneity near the Oceanographer Transform, Mid-Atlantic Ridge. *Nature*, 325, 217-223.
- Ryan, J. and Langmuir, C. (1987). The systematics of lithium abundances in young volcanic rocks. *Geochim. Cosmochim. Acta*, 51, 1727-1741.
- Klein, E. and Langmuir, C. (1987). Global correlations of ocean ridge basalt chemistry, axial depth, crustal thickness. *J. Geophys. Res.* 92, 8089-8115.
- Langmuir, C. (1987). A magma chamber observed? *Nature*, 326, 15-16.
- Detrick, R. and Langmuir, C. (1987). "Geometry and dynamics of magma chambers", in *The Mid-oceanic Ridge – A Dynamic Global System*, Workshop Proceedings, National Academy Press, pp. 121-150.
- Perfit, M., Langmuir, C. et al. (1987). "Geochemistry and petrology of volcanic rocks from the Woodlark Basin: Addressing questions of ridge subduction", in *Marine Geology, Geophysics and Geochemistry of the Woodlark Basin – Solomon Islands*, B. Taylor and N. Exon (eds.), Circum-Pacific Earth Science Series, v. 7, pp. 113-154.
- Johnson, R., Jaques, A., Langmuir C. et al. (1987). "Ridge subduction and fore-arc volcanism: Petrology and geochemistry of rocks dredged from the western Solomon arc and the Woodlark Basin", in *Marine Geology, Geophysics and Geochemistry of the Woodlark Basin – Solomon Islands*, B. Taylor and N. Exon (eds.), Circum-Pacific Earth Science Series, v. 7, pp. 155-226.
- Ryan, J. and Langmuir, C. (1988). Beryllium systematics in young volcanic rocks: Implications for <sup>10</sup>Be. *Geochim. Cosmochim. Acta*, 52, 237-244.
- Klein, E., Langmuir, C., Zindler, A., Staudigel, H., Hamelin, B. (1988). Isotope evidence of mantle convection boundary at the Australian-Antarctic Discordance. *Nature*, 333, 623-629.
- Plank, T. and Langmuir, C. (1988). An evaluation of the global variations in the major element chemistry of arc basalts. *Earth Planet. Sci. Lett.*, 90, 349-370.
- Klein, E. and Langmuir, C. (1989). Local versus global variations in ocean ridge basalt composition: A reply. *J. Geophys. Res.*, 94, 4241-4252.
- Langmuir, C. (1989). Geochemical Consequences of *In Situ* Crystallization. *Nature*, 340, 199-205.
- Weaver, J. and Langmuir, C. (1990). Calculation of phase equilibrium in mineral-melt systems. *Computers and Geosciences*, 16, 1-19.
- Langmuir, C. (1990). Ocean ridges spring surprises. *Nature*, 344, 575-688.
- Fryer, P., Taylor, B., Langmuir, C., Hochstaedter, A. (1990). Petrology and geochemistry of lavas from the Sumisu and Torishima backarc rifts. *Earth Planet. Sci. Lett.*, 100, 161-178.
- Taylor, B., Brown, G., Fryer, P., Gill, J., Hochstaedter, A., Hotta, H., Langmuir, C., Leinen, M., Nishimura, A., Urabe, T. (1990). Alvin-SeaBeam Studies of the Sumisu Rift, Izu-Bonin Arc. *Earth and Planet. Sci. Lett.*, 100, 127-147.
- Klein, E., Langmuir, C., Staudigel, H. (1991). Geochemistry of basalts from the Southeast Indian Ridge, 115°E-138°E. *J. Geophys. Res.*, 96, 2089-2107.
- Miller, D., Langmuir, C., Goldstein, S., Franks, A. (1992). The importance of parental magma composition to calc-alkaline and tholeiitic evolution: Evidence from Umnak Island in the Aleutians. *J. Geophys. Res.*, 97, 321-343.
- Plank, T. and Langmuir, C. (1992). Effects of the melting regime on the composition of the oceanic crust. *J. Geophys. Res.*, 97, 19,749-19,770.
- Ryan, J. and Langmuir, C. (1992). The systematics of boron abundances in young volcanic

- rocks. *Geochim. Cosmochim. Acta.*, 57, 1489-1498.
- Reynolds, J., Langmuir, C., Bender, J., Kastens, K., Ryan W. (1992). Spatial and temporal variability in the geochemistry of basalts from the East Pacific Rise. *Nature*, 359, 493-499.
- Langmuir, C., Klein, E., Plank, T. (1992). Petrological systematics of mid-ocean ridge basalts: Constraints on melt generation beneath ocean ridges. *AGU Monograph*, 71, 183-280.
- Langmuir, C. (1992). Evaluation of the relationships among segmentation, hydrothermal activity and petrological diversity of the Mid-Atlantic Ridge, Cruise Report, Tech. Report No. LDEO-92-3.
- Plank, T. and Langmuir, C. (1993). Tracing trace elements from sediment input to volcanic output at subduction zones. *Nature*, 362, 739-742.
- Langmuir, C. (1993). Lucky Strike / Alvin Expedition, Cruise Report, Tech. Report No. LDEO-93-2.
- Miller, D., Goldstein, S., Langmuir, C. (1993). Ce/Pb and Pb isotope ratios in arc magmas and the enrichment of Pb in the continents. *Nature*, 368, 514-519.
- Langmuir, C. (1993). Deep thoughts on the mantle. *Nature*, 364, 191-192.
- Plank, T. and Langmuir, C. (1994). Reply to Varne. *Nature*, 367, 224-225.
- Langmuir, C. (1994) Water and the solid Earth. *Nature*, 369, 704-705.
- Christie, D. and Langmuir, C. (1994). Automated XY Plots from Microsoft Excel. *Computers & Geosciences*, 20, 47-52.
- Perfit, M., Fornari, D., Smith, M., Bender, J., Langmuir, C., Haymon, R. (1994). Small-scale spatial and temporal variations in mid-ocean ridge crest magmatic processes. *Geology*, 22, 375-379.
- Langmuir, C. (1994). Major element heterogeneity in the mantle: Constraints from a general model for basalt petrology. *Mineralogical Magazine*, 58, 510-513.
- Goldstein, S., Miller, D., Langmuir, C., Hofmann, A. (1994). How large is the mantle source of ocean island basalts? *Mineralogical Magazine*, 58, 336-339.
- Kinzler, R. and Langmuir, C. (1995). Minute mantle melts. *Nature*, 375, 274-275.
- Langmuir, C. (1995). Deep sea thrills, review of *Explorations: My Quest for Adventure and Discovery Under the Sea*, R. D. Ballard with M. McConnell, Hyperion, 1995, pp 407, *Nature*, 376, 221.
- Plank, T., Spiegelman, M., Langmuir, C., Forsyth, D. (1995). The meaning of "Mean F": Clarifying the mean extent of melting at ocean ridges. *J. Geophys. Res.*, 100, 15,045-15,052.
- Ryan, J., Leeman, W., Morris, J., Langmuir, C. (1996). The boron systematics of intraplate lavas: Implications for crust and mantle evolution. *Geochim. Cosmochim. Acta*, 60, 415-422.
- Bourdon, B., Langmuir, C., Zindler, A. (1996). Ridge-hotspot interaction at the Mid-Atlantic Ridge between 37°30' and 40°31'N: The U-Th disequilibrium evidence. *Earth Planet. Sci. Letts.*, 142, 175-189.
- Bourdon, B., Zindler, A., Elliott, T., Langmuir, C. (1996). Constraints on mantle melting at mid-ocean ridges from global <sup>238</sup>U-<sup>230</sup>Th disequilibrium data. *Nature*, 384, 231-235.
- Van Dover, C., Desbruyeres, D., Segonzac, M., Comtet, T., Saldanha, L., Fiala-Medioni, A., Langmuir, C. (1996). Biology of the Lucky Strike hydrothermal field. *Deep-Sea Research I*, 43, 1509-1529.
- Langmuir, C., Humphris, S., Fornari, D., Van Dover, C., Von Damm, K., Tivey, M., Colodner, D., Charlou, J.-L., Desonie, D., Wilson, C., Fouquet, Y., Klinkhammer, G., Bougault, H. (1997). Hydrothermal vents near a mantle hot spot: The Lucky Strike vent field at 37°N on the Mid-Atlantic Ridge. *Earth & Planet. Sci. Lett.*, 148, 69-91.
- Reynolds, J. and Langmuir, C. (1997). Petrological systematics of the mid-Atlantic ridge south of Kane: Implications for ocean crust formation. *J. Geophys. Res.*, 102, 14,915-14,946.
- Niu, Y., Langmuir, C., Kinzler, R. (1997). The Origin of abyssal peridotites: A new perspective. *Earth & Planet. Sci. Lett.*, 152, 251-265.
- Plank, T. and Langmuir, C. (1998). The chemical composition of subducting sediment and its consequences for the crust and mantle. *Chem. Geol.*, 145, 325-394.
- Staudigel, H., Albarède, F., Blichert-Toft, J., Edmond, J., McDonough, B., Jacobsen, S., Keeling, R., Langmuir, C., Nielsen, R., Plank, T., Rudnick, R., Shaw, H., Shirey, S., Veizer, J., White, W. (1998). Geochemical Earth Reference Model (GERM): Description of the initiative. *Chem. Geol.*, 145, 153-159.
- Dosso, L., Bougault, H., Langmuir, C., Bollinger, C., Bonnier, O., Etoubleau, J. (1999). The age and distribution of mantle heterogeneity along the Mid-Atlantic Ridge (31 - 41°N). *Earth Planet. Sci. Lett.*, 170, 269-286.

- Lehnert, K., Su, Y., Langmuir, C. (1999). A global geochemical database structure for rocks. *Geochem. Geophys. Geosyst.* 1, Paper # 1999GC000026.
- Humler, E., Langmuir, C., Daux, V. (1999). Depth vs. age: New perspectives from the chemical compositions of ancient crust. *Earth Planet. Sci Lett.*, 173, 7-23.
- Bourdon, B., Goldstein, S., Murrell, M., Langmuir, C. (2000). Evidence from <sup>10</sup>Be and U series disequilibria on the possible contamination of mid-ocean ridge basalt glasses by sedimentary material. *Geochem. Geophys. Geosyst.*, 1 (8), doi:10.1029/2000GC000047.
- Class, C., Miller, D., Goldstein, S., Langmuir, C. (2000). Distinguishing melt and fluid subduction components in Umnak volcanics, Aleutian Arc. *Geochem. Geophys. Geosyst.*, 1, Paper # 1999GC000010.
- Reynolds, J. and Langmuir, C. (2000). Identification and implications of off-axis lava flows around the East Pacific Rise. *Geochem. Geophys. Geosyst.*, 1, Paper # 1999GC000033.
- Yi, W., Halliday, A., Alt, J., Lee, D., Rehkamper, M., Garcia, M., Langmuir, C., Su, Y. (2000). Cadmium, indium, tin, terrarium, and sulfur in oceanic basalts: Implications for chaocophile element fractionation in the Earth. *J. Geophys. Res.*, 105, 18927-18948.
- Castillo, P., Klein, E., Bender, J., Langmuir, C., Shirey, S., Batiza, R., White, W. (2000). Petrology and Sr, Nd, and Pb isotope geochemistry of mid-ocean ridge basalt glasses from the 11°45'N to 15°00'N segment of the East Pacific Rise. *Geochem. Geophys. Geosyst.*, 1 (11), doi:10.1029/1999GC000024.
- Baker, E., Cormier, M., Langmuir, C., Zavala, K. (2001). Hydrothermal plumes along segments of contrasting magmatic influence, 15°20'-18°30'N, East Pacific Rise: Influence of axial faulting. *Geochem. Geophys. Geosyst.*, 2 (9), doi:10.1029/2000GC000165.
- Saal, A., Hauri, E., Langmuir, C., Perfit, M. (2002). Vapour undersaturation in primitive mid-ocean-ridge basalt and the volatile content of Earth's upper mantle. *Nature*, 419, 451-455.
- Dixon, J., Leist, L., Langmuir, C., Schilling J.-G. (2002). Recycled dehydrated lithosphere observed in plume-influenced mid-ocean-ridge basalt. *Nature*, 420, 385-389.
- Cottrell, E., Spiegelman, M., Langmuir, C.H. (2002). Consequences of diffusive reequilibration for the interpretation of melt inclusions. *Geochem. Geophys. Geosyst.*, 3 (5), 1026, doi:10.1029/2001GC000205.
- Kempton, P., Pearce, J., Barry, T., Fitton, J., Langmuir, C., Christie, D. (2002). Sr-Nd-Pb-Hf isotope results from ODP leg 187: Evidence for mantle dynamics of the Australian-Antarctic discordance and origin of the Indian MORB source. *Geochem. Geophys. Geosyst.*, 3 (12), 1074, doi:10.1029/2002GC000320.
- Edmonds, H., Michael, P., Baker, E., Connelly, D., Snow, J., Langmuir, C., Dick, H., Mühe, R., German, C., Graham, D. (2003). Discovery of abundant hydrothermal venting on the ultra-slow spreading Gakkel Ridge, Arctic Ocean. *Nature* 421, 252-256.
- Gómez-Tuena A., LaGatta, A., Langmuir, C., Goldstein, S., Ortega-Gutiérrez, F., Carrasco-Núñez, G. (2003). Temporal control of subduction magmatism in the eastern Trans-Mexican Volcanic Belt: Mantle sources, slab contributions, and crustal contamination. *Geochem. Geophys. Geosyst.*, 4 (8), 8912, doi:10.1029/2003GC000524.
- Katz R., Spiegelman, M., Langmuir, C. (2003). A new parameterization of hydrous mantle melting. *Geochem. Geophys. Geosyst.*, 4 (9), 1073, doi:10.1029/2002GC000433.
- Asimow, P. and Langmuir, C. (2003). The importance of water to oceanic melting regimes. *Nature*, 421, 815-820.
- Su Y., Langmuir, C., Asimow, P. (2003). PetroPlot: A plotting and data management tool set for Microsoft Excel. *Geochem. Geophys. Geosyst.*, 4 (3), 1030, doi:10.1029/2002GC000323.
- Michael, P., Langmuir, C., Dick, H., Snow, J., Goldstein, S., Graham, D., Lehnert, K., Kurras, G., Jokat, W., Mühe, R., Edmonds, H. (2003). Magmatic and amagmatic seafloor generation at the ultraslow-spreading Gakkel ridge, Arctic Ocean. *Nature*, 423, 956-961.
- Straub S., Layne, G., Schmidt, A., Langmuir, C. (2004). Volcanic glasses at the Izu arc volcanic front: New perspectives on fluid and sediment melt recycling in subduction zones. *Geochem. Geophys. Geosyst.*, 5, Q01007, doi:10.1029/2002GC000408.
- Saal, A., Hauri, E., Langmuir, C., Perfit, M. (2004). Earth science: Role of *f*O<sub>2</sub> on fluid saturation in oceanic basalt. *Nature*, 429.

- Langmuir, C. (2004). Making Waves: The voyage of HMS Challenger launched the science of oceanography. *Nature*, 429, 131.
- Cooper, K., Eiler, J., Asimow, P., Langmuir, C. (2004). Oxygen isotope evidence for the origin of enriched mantle beneath the Mid-Atlantic Ridge. *Earth Planet. Sci. Lett.*, 220 (3-4), 297-316.
- Carlut, J., Cormier, M.-H., Kent, V., Donnelly, K., Langmuir, C. (2004). Timing of volcanism along the northern East Pacific Rise based on paleointensity experiments on basaltic glasses. *J. Geophys. Res.*, 109, B04104, doi:10.1029/2003JB002672.
- Baker, E., Edmonds, H., Michael, P., Bach, W., Dick, H., Snow, J., Walker, S., Banerjee, N., Langmuir, C. (2004). Hydrothermal venting in magma deserts: The ultraslow-spreading Gakkel and South West Indian Ridges. *Geochem. Geophys. Geosyst.*, 5 (8), Q08002, doi: 10.1029/2004GC000712.
- Asimow, P., Dixon, J., Langmuir, C. (2004). A hydrous melting and fractionation model for mid-ocean ridge basalts: Application to the Mid-Atlantic Ridge near the Azores. *Geochem. Geophys. Geosyst.*, 5, Q01E16, doi:10.1029/2003GC000568.
- Donnelly, K., Goldstein, S., Langmuir, C., Spiegelman, M. (2004). Origin of enriched ocean ridge basalts and implications for mantle dynamics. *Earth Planet. Sci. Lett.*, 226, 347-366.
- German, C., Baker E., Connelly, D., Lupton, J., Resing, J., Prien, R., Walker, S., Edmonds, H., Langmuir, C. (2006). Hydrothermal exploration of the Fonualei Rift and spreading center and NE Lau spreading center. *Geochem. Geophys. Geosyst.*, 7 (11), Q11022, doi:10.1029/2006GC001324.
- Langmuir, C., Bezos, A., Escrig, S., Parman, S. (2006). Chemical systematics and hydrous melting of the mantle in back-arc basins. *AGU Geophysical Monograph Series* 166, 87-146.
- Langmuir, C. and Forsyth, D. (2007). Mantle melting beneath mid-ocean ridges. *Oceanography* 20 (1), 78-89.
- Gómez-Tuena, A., Langmuir, C., Goldstein, S., Straub, S., Ortega-Gutiérrez, F. (2007). Geochemical evidence for slab melting in the Trans-Mexican Volcanic Belt. *J. Petrology*, 48 (3), 537-562.
- Rodriguez, C., Selles, D., Dungan, M., Langmuir, C., Leeman, W. (2007). Adakitic dacites formed by intracrustal crystal fractionation of water-rich parent magmas at Nevado de Longavi volcano. *J. Petrol.*, 48, 2033-2061, doi:10.1093/petrology/egm049.
- Goldstein, S., Soffer, G., Langmuir, C., Lehnert, K., Graham, D., Michael, P. (2008). Origin of a 'Southern Hemisphere' geochemical signature in the Arctic upper mantle. *Nature*, 453, 89-93, doi:10.1038/nature06919.
- Straub, S., LaGatta A., Martin-Del Pozzo, A., Langmuir, C. (2008). Evidence from high-Ni olivines for a hybridized peridotite/pyroxenite source for orogenic andesites from the central Mexican Volcanic Belt. *Geochem. Geophys. Geosyst.*, 9, Q03007, doi:10.1029/2007GC001583.
- Christopher R. German, Dana R. Yoerger, Michael Jakuba,1, Timothy M. Shanka Charles H. Langmuir, Ko-ichi Nakamura (2008) Hydrothermal exploration with the Autonomous Benthic Explorer, Deep-Sea Research I 55 (2008) 203–219
- Escartin, J., Smith, D., Cann, J., Schouten, H., Langmuir, C., and Escrig, S. (2008). Central role of detachment faults in accretion of slow-spreading oceanic lithosphere. *Nature*, 455, 790-794, doi:10.1038/nature07333.
- Tomascak, P., Langmuir, C., le Roux, P., Shirey, S. (2008). Lithium isotopes in global mid-ocean ridge basalts. *Geochimica et Cosmochimica Acta*, 72, I 6, 1626-1637, doi:10.1016/j.gca.2007.12.021.
- Straub, S. M., LaGatta, A. B., Martin-Del Pozzo, A. L. and Langmuir C. H. (2008). Evidence from high-Ni olivines for a hybridized peridotite/pyroxenite source for orogenic andesites from the central Mexican Volcanic Belt. *Geochem. Geophys. Geosyst.*, 9, Q03007, doi:10.1029/2007GC001583.
- Li Z., Yang S., Chen H., Langmuir C., Yu X., Lin X., Li Y. (2009). Chronology and geochemistry of Taxinan Permian basalts from the Tarim basin: Evidence for Permian plume magmatism. *Acta Petrologica Sinica*, 24(5): 959-970.
- Bézos, A., S. Escrig, C.H. Langmuir, P. J. Michael, and P. D. Asimow (2009). Origins of chemical diversity of back-arc basin basalts: A segment-scale study of the Eastern Lau Spreading Center, *J. Geophys. Res.*, 114, B06212, doi:10.1029/2008JB005924.
- Escrig, S., A. Bézos, S. L. Goldstein, C.H. Langmuir, and P. J. Michael (2009). Mantle source variations beneath the Eastern Lau Spreading Center and the nature of subduction components in the Lau basin–Tonga arc system. *Geochem. Geophys. Geosyst.* 10, Q04014, doi:10.1029/2008GC002281.
- Huybers, P., and Langmuir, C. (2009). Feedback between deglaciation and volcanic emissions of CO<sub>2</sub>. *Earth Planet. Sci. Lett.* 286, 479–491, doi:10.1016/j.epsl.2009.07.014.

- Cooper, K. M., J. M. Eiler, K. W. W. Sims, and C. H. Langmuir (2009), Distribution of recycled crust within the upper mantle: Insights from the oxygen isotope composition of MORB from the Australian-Antarctic Discordance, *Geochem. Geophys. Geosyst.*, 10, Q12004, doi:10.1029/2009GC002728.
- Simons, K.K. et al. (2010). Lithium isotopes in Guatemalan and Franciscan HP-LT rocks: Insights into the role of sediment-derived fluids during subduction. *Geochimica et Cosmochimica Acta*, 74(12): 3621-3641.
- Gale, A., Escrig, S., Gier, E.J., Langmuir, C.H. and Goldstein, S.L. (2011). Enriched basalts at segment centers: The Lucky Strike (37 degrees 17 ' N) and Menez Gwen (37 degrees 50 ' N) segments of the Mid-Atlantic Ridge. *Geochemistry Geophysics Geosystems*, 12, Q06016, doi:10.1029/2010GC003446.
- Kiser, E., Ishii, M., Langmuir, C.H., Shearer, P.M. and Hirose, H. (2011). Insights into the mechanism of intermediate-depth earthquakes from source properties as imaged by back projection of multiple seismic phases. *Journal of Geophysical Research-Solid Earth*, 116, B06310, doi:10.1029/2010JB007831.
- Salter, V.J.M., Mallick, S., Hart, S.R., Langmuir, C.H. and Stracke, A. (2011). Domains of depleted mantle: New evidence from hafnium and neodymium isotopes. *Geochemistry Geophysics Geosystems*, 12, Q08001, doi:10.1029/2011GC003617.
- Salter, V.J.M., Mallick, S., Hart, S.R., Langmuir, C.H. and Stracke, A. (2011). Domains of depleted mantle: New evidence from hafnium and neodymium isotopes. *Geochemistry Geophysics Geosystems*, 12, Q10017, doi:10.1029/2011GC003874
- Reubi, O., Bourdon. B., Dungan, M.A., Koorneef, J.M., Selles, D., Langmuir, C.H., Aciego, S. (2011). Assimilation of the plutonic roots of the Andean arc controls variations in U-series disequilibria at Volcan Llaima, Chile. *Earth and Planetary Science Letters*, 303(1-2): 37-47.
- Laubier, M.L., Gale, A., Langmuir, C.H. (2012). Melting and Crustal Processes at the FAMOUS Segment (Mid-Atlantic Ridge): New Insights from Olivine-Hosted Melt Inclusions from Multiple Samples, *Journal of Petrology*, 53(4):665-698, doi: 10.1093/petrology/egr075.
- Li, Z., Li, Y., Chen, H., Santosh, M., Yang, Sh., Xu, Y., Langmuir, C.H., Chen, Zh., Yu, X., Zou, S. (2012). Hf isotopic characteristics of the Tarim Permian large igneous province rocks of NW China: Implication for the magmatic source and evolution. *Journal of Asian Earth Sciences*, 49:191-202, doi: 10.1016/j.jseaes.2012.11.021.
- Tivey, M.K. Becker, E., Beinart, C.R., Girguis, P.R., Langmuir, C.H., Michael, P.J., Reysenbach, A.L. (2012). Links from mantle to microbe at the Lau Integrated Study Site: Insights from back-arc spreading center. *Oceanography*, 25(1):62-77, doi:10.5670/oceanog.2012.04.
- Escrig, S., A. Bézou, C. H. Langmuir, P. J. Michael, and R. Arculus. (2012). Characterizing the effect of mantle source, subduction input and melting in the Fonualei Spreading Center, Lau Basin: Constraints on the origin of the boninitic signature of the back-arc lavas. *Geochem. Geophys. Geosyst.*, 13, Q10008, doi:10.1029/2012GC004130
- Straub, S. M., Gómez-Tuena, A., Zellmer, G. F., Espinasa-Perena, R., Stuart, F. M., Cai, Y., Langmuir, C. H., Martin-Del Pozzo, A. L. & Mesko, G. T. (2012). The Processes of Melt Differentiation in Arc Volcanic Rocks: Insights from OIB-type Arc Magmas in the Central Mexican Volcanic Belt. *Journal of Petrology*, 1-37. doi:10.1093/petrology/egs081
- Turner, S. J., Izbekov, P., Langmuir, C. H. (2012). The magma plumbing system of Bezymianny Volcano: Insights from a 54 year time series of trace element whole-rock geochemistry and amphibole compositions. *Journal of Volcanology and Geothermal Research*, doi:10.1016/j.jvolgeores.2012.12.014.
- Yin-Qi Li, Zi-Long Li, Ya-Li Sun, M. Santosh, Charles H. Langmuir, Han-Lin Chen, Shu-Feng Yan, Zhong-Xing Chen, Xing Yu (2012). Platinum-group elements and geochemical characteristics of the Permian continental flood basalts in the Tarim Basin, northwest China: Implications for the evolution of the Tarim Large Igneous Province. *Chemical Geology* 238 278-289, doi:10.1016/j.chemgeo.2012.03.007
- S. Straub, A. Gomez-Tuena, G. Zellmer, R. Espinas-Perena, F. Stuart, Y. Cai, C. Langmuir, A. Martin-del-Pozzo and G. Mesko (2013) The Processes of Melt Differentiation in Arc Volcanic Rocks: Insights from OIB-type Arc Magmas in the Central Mexican Volcanic Belt *J. Petrology* 54 665-701.



- Gale, A., M. Laubier, S. Escrig and C. H. Langmuir (2013) Constraints on melting processes and plume-ridge interaction from comprehensive study of the FAMOUS and North Famous segments, Mid-Atlantic Ridge, *Earth and Planet. Sci. Lett.* 365 209-220 doi: \10.1016/j.epsl.2013.01.022
- Gale, A., C. A. Dalton, C. H. Langmuir, Y. Su, and J.-G. E. Schilling (2013). The mean composition of ocean ridge basalts, *Geochem. Geophys. Geosyst.*, doi:10.1029/2012GC004334.
- Langmuir, C. H. (2013) Older and Hotter, News and Views *Nature Geoscience* 6 332-333.
- Cai, Y. A LaGatta, S.L. Goldstein, C. H. Langmuir, A. Gomez-Tuena, A.Martin-del-Pozzo, G. Carrasco-Nunez (2014) Hafnium isotope evidence for slab melt contributions in the Central Mexican Volcanic Belt and implications for slab melting in hot and cold slab arcs, *Chemical Geology*, 377 45-55.
- Laubier, M., T.L Grove and C. H. Langmuir (2014) Trace element mineral/melt partitioning for basaltic and basaltic andesitic melts: An experimental and laser ICP-MS study with application to the oxidation state of mantle source regions, *Earth Planet. Sci. Lett.* 392, 265-278.
- Dalton, C., C. H. Langmuir and A. Gale (2014) Geophysical and geochemical evidence for deep temperature variations beneath mid-ocean ridges, *Science* 344 80. doi: 10.1126/science.1249466
- Gale, A., C. H. Langmuir and C. Dalton (2014) The global systematics of ocean ridge basalts and their origin, *J. Petrology* 55 6 1051-1082 doi:10.1093/petrology/egu017
- Ray, D., S. Misra, M. Widdowson, C. H. Langmuir (2014) A common parentage for Deccan Continental Flood Basalt and Central Indian Ocean Ridge Basalt? A geochemical and isotopic approach. *J. Asian Earth Sci.* 84 188-200.
- Yin-Qi Li, Zi-Long Li, Xing Yu, C. H. Langmuir, M. Santosh, Shu-Feng Yang, Han-Lin Chen, Zhong-Li Tang, B. Song and S. Zu, (2014) Origin of Early Permian zircons in Keping basalts and magma evolution of the Tarim Large Igneous Province (northwestern China) *Lithos* 204 47-58.
- Crowley, J. W., R. F. Katz1, P. Huybers, C. H. Langmuir, S-H. Park (2015) Glacial cycles drive variations in the production of oceanic crust, *Science* 347, 6227, 1237-1240, doi: 10.1126/science.126150
- Turner, S. J. and C. H. Langmuir (2015a) The global chemical systematics of arc front stratovolcanoes: Evaluating the role of crustal processes, *Earth Planet. Sci. Lett.*, 422, 182-193.
- Turner, S.J. and C. H. Langmuir (2015b) What processes control the chemical compositions of arc front stratovolcanoes?, *Geochem. Geophys. Geosys.* doi: 10.1002/2014GC005633
- Crowley, J. W., Katz1, R.F., Huybers, P., Langmuir, C.H., Park, S-H. (2015) Response to comment on glacial cycles drive variations in the production of oceanic crust *Science* 349, 6252, 1065-b doi: 10.1126/science.aab3497
- Sun, H., Li, Y., Li, Z., Zou, S., Langmuir, C.H., Chen, H., Yang1, S., Ren, Z. (2016) Estimating the Parental Magma Composition and Temperature of the Xiaohaizi Cumulate-Bearing Ultramafic Rock: Implication for Magma Evolution of the Tarim Large Igneous Province, Northwestern China. *Journal of Earth Science*, Vol. 27, No. 3, p. 519–528, doi:10.1007/s12583-016-0676-4
- Costa, K.M., McManus, J.F., Boulahanis, B., Carbotte, S.M., Winckler, G., Huybers, P.J., Langmuir, C.H. (2016) Sedimentation, stratigraphy and physical properties of sediment on the Juan de Fuca Ridge. *Marine Geology* 380, 163–173, doi.org/10.1016/j.margeo.2016.08.003
- Turner, S.J., Langmuir, C.H., Katz, R.F., Dungan, M.A., Escrig, S. (2016) Parental arc magma compositions dominantly controlled by mantle-wedge thermal structure. *Nature Geoscience* 9 (10),772-776, doi:10.1038/ngeo2788
- Middleton, J.L., Langmuir, C.H., Mukhopodhyay, S., McManus, J. and Mitrovica, J. (2016), Hydrothermal iron flux variability following rapid sea level changes. *Geophys. Res. Lett.* 43 8 3838-3856. [doi.org/10.1002/2016GL068408](https://doi.org/10.1002/2016GL068408)
- Huybers, P.J., Langmuir, C.H. (2017) Delayed CO<sub>2</sub> emissions from mid-ocean ridge volcanism as a possible cause of late-Pleistocene glacial cycles. *Earth and Planet. Sci. Lett.* 457 238-249, doi: 10.1016/j.epsl.2016.09.021
- Dixon J.E., Bindeman I.N., Kingsley R.H., Simons K.K., le Roux P.J., Hajewski T.R., Swart P., Langmuir C.H., Ryan J.G., Walowski K.J., Wada I., Wallace P.J. (2017) Light Stable Isotopic Compositions of Enriched Mantle Sources: Resolving the Dehydration Paradox. *Geochem. Geophys. Geosyst.*, doi:10.1002/2016GC006743

- Ferguson, D.J., Li, Y., Langmuir, C.H., Costa, K.M., McManus, J.F., Huybers, P.J., Carbotte, S.M. (2017) A 65 k.y. time series from sediment-hosted glasses reveals rapid transitions in ocean ridge magmas. *Geology* 45 (6), 491-494, doi:10.1130/g38752.1
- Turner, S.J., Langmuir, C.H., Dungan, M.A., Escrig, S. (2017) The importance of mantle wedge heterogeneity to subduction zone magmatism and the origin of EM1. *Earth and Planet. Sci. Lett* 472 216-228, doi:10.1016/j.epsl.2017.04.051
- Costa, K. M., McManus, J. F., Middleton, J. L., Langmuir, C. H., Huybers, P. J., Winckler, G., Mukhopadhyay, S. (2017) Hydrothermal deposition on the Juan de Fuca Ridge over multiple glacial–interglacial cycles. *Earth and Planet. Sci. Lett* 479, 120-132, doi:10.1016/j.epsl.2017.09.006
- Langmuir, CH (2018). Mid-ocean Ridge Basalts, Encyclopedia of Earth Sciences, 924-932.
- Middleton J. L., Mukhopadhyay S., Langmuir C. H., McManus J. F., and Huybers P. (2018) Millennial-scale variations in dustiness recorded in Mid-Atlantic sediments from 0 to 70 ka. *Earth and Planet. Sci. Lett* 482, 12-22, doi:10.1016/j.epsl.2017.10.034
- Costa, K.M., Anderson, R.F., McManus, J.F., Winckler, G., Middleton J. L., Langmuir, C. H. (2018) Trace element (Mn, Zn, Ni, V) and authigenic uranium (aU) geochemistry reveal sedimentary redox history on the Juan de Fuca Ridge, North Pacific Ocean. *Geochimica et Cosmochimica Acta*. doi.org/10.1016/j.gca.2018.02.016
- Wu, F., Qi, Y., Perfit, M.R., Gao, Y., Langmuir, C.H., Wanless, V. Dorsey, Yu, H, Huang, F. (2018) Vanadium isotope compositions of mid-ocean ridge lavas and altered oceanic crust. *Earth and Planet. Sci. Lett Letters* 493, 128-139, doi.org/10.1016/j.epsl.2018.04.009
- Wu, T., Li, Z-L., Zhou, J., Mao, J-R., Langmuir, C.H., Wang, C-L., Zhang, F-J., Gao, X., Chen, R, Lin, Q-L, Zhang, Y, Kamei, A (2018) Petrogenesis of the Late Mesozoic Magnesian and Ferroan Granites in Northwest Zhejiang, Southeast China, and Their Implications. *The Journal of Geology*, Vol. 126 (4), 407-425, <https://doi.org/10.1086/697691>
- M Le Voyer, EH Hauri, E Cottrell, KA Kelley, VJM Salters, CH Langmuir... (2018) Carbon Fluxes and Primary CO<sub>2</sub> Contents along the Global Mid-ocean Ridge System. *Geochemistry, Geophysics, Geosystems* 20 (3)
- Park, SH, Langmuir CH, KWW Sims, J Blichert-Toft, SS Kim, SR Scott, ...(2019). An isotopically distinct Zealandia-Antarctic mantle domain in the Southern Ocean  
*Nature Geoscience*, 12 3 206-214
- Mallick, S. Slaters, VJM and Langmuir, CH (2019) Geochemical variability along the northern east Pacific Rise; Coincident source composition and ridge segmentation *Geochemistry, Geophysics, Geosystems* 20 (4) 1889-1911.
- Middleton, J, Mukhopodhyay, S., Costa, KM, Winckler, G. McManus, JF. Langmuir, CH and Huybers, P (2020) The spatial footprint of hydrothermal scavenging on <sup>230</sup>ThXS-derived mass accumulation rates. *Geochmica Cosmochimica Acta*, in press.
- Boulahanis, B., Carbotte, S. M., Huybers, P. J., Nedimović, M. R., Aghaei, O., Canales, J. P., & Langmuir, C. H. (2020). Do sea level variations influence mid-ocean ridge magma supply? A test using crustal thickness and bathymetry data from the East Pacific Rise. *Earth and Planetary Science Letters*, 535, 116121. <https://doi.org/10.1016/j.epsl.2020.116121>
- Yang, A. Y., Langmuir, C. H., Cai, Y., Michael, P., Goldstein, S. L., & Chen, Z. (2021). A subduction influence on ocean ridge basalts outside the Pacific Subduction Shield. *Nature Communications*, 12(1). <https://doi.org/10.1038/s41467-021-25027-2>
- Sun, W., Langmuir, C. H., Ribe, N. M., Zhang, L., Sun, S., Li, H., Li, C., Fan, W., Tackley, P. J., & Sanan, P. (2021). Plume-ridge interaction induced migration of the Hawaiian-emperor seamounts. *Science Bulletin*. <https://doi.org/10.1016/j.scib.2021.04.028>
- Cai, Y., Yang, A. Y., Goldstein, S. L., Langmuir, C. H., Michael, P. J., Cochran, J. R., Zhang, W., Wang, D., & Bolge, L. (2021). Multi-stage melting of enriched mantle components along the eastern Gakkel Ridge. *Chemical Geology*, 586, 120594. <https://doi.org/10.1016/j.chemgeo.2021.120594>
- Sellés, D., Dungan, M., Langmuir, C., Rodríguez, A. C., & Leeman, W. P. (2022). Magma and mineral composition response to increasing slab-derived fluid flux: Nevado de Longaví Volcano, southern Chilean Andes. *Frontiers in Earth Science*, 10. <https://doi.org/10.3389/feart.2022.846997>

- Turner, S. J., & Langmuir, C. H. (2022). An evaluation of five models of Arc Volcanism. *Journal of Petrology*, 63(3). <https://doi.org/10.1093/petrology/egac010>
- Zhao, S.-Y., Yang, A. Y., Langmuir, C. H., & Zhao, T.-P. (2022). Oxidized primary arc magmas: Constraints from Cu/Zr Systematics in global arc volcanics. *Science Advances*, 8(12). <https://doi.org/10.1126/sciadv.abk0718>
- Turner, S. J., & Langmuir, C. H. (2022). Sediment and ocean crust both melt at subduction zones. *Earth and Planetary Science Letters*, 584, 117424. <https://doi.org/10.1016/j.epsl.2022.117424>
- Turner, S. J., & Langmuir, C. H. (2022). A quantitative framework for global variations in Arc Geochemistry. *Earth and Planetary Science Letters*, 584, 117411. <https://doi.org/10.1016/j.epsl.2022.117411>
- Sun, W., Langmuir, C. H., Ribe, N. M., & Zhang, L. (2022). Reply to “is ‘plume interaction induced migration of the Hawaiian-emperor seamounts’ a step too far?” *Science Bulletin*, 67(12), 1221–1223. <https://doi.org/10.1016/j.scib.2022.04.014>
- Yang, A. Y., Langmuir, C., & Michael, P. (2022). The significance of recycled oceanic mantle lithosphere beneath the Arctic Gakkel Ridge. <https://doi.org/10.21203/rs.3.rs-1668228/v1>
- Huybers, P., Liautaud, P., Proistosescu, C., Boulahanis, B., Carbotte, S. M., Katz, R. F., & Langmuir, C. (2022). Influence of late pleistocene sea-level variations on midocean ridge spacing in faulting simulations and a global analysis of Bathymetry. *Proceedings of the National Academy of Sciences*, 119(28). <https://doi.org/10.1073/pnas.2204761119>