

## CURRICULUM VITAE 5<sup>th</sup> March 2008

### Michael J. Russell, BSc., PhD.

Planetary Science and Life Detection

Section 3220, MS: 183-601

Jet Propulsion Laboratory

California Institute of Technology

4800 Oak Grove Drive

Pasadena, CA 91109-8099, USA

[mrussell@jpl.nasa.gov](mailto:mrussell@jpl.nasa.gov)

<http://www.gla.ac.uk/Project/originoflife/htm>



### Positions held

NASA Senior Research Fellow, JPL/California Institute of Technology, 2006-present

Distinguished Visiting Scientist, JPL/California Institute of Technology, 2005-present

CNRS Professor, University of Grenoble, 2004-5

Visiting Professor, Heinrich-Heine-Universität Düsseldorf, 2002-present

Dixon Research Professor, Scottish Universities Environmental Research Centre, 1999-2004,

Professor of Applied Geology, Glasgow University, 1990-1999,

Professor/HoD, Applied Geology Department, Strathclyde University, Glasgow, Scotland, 1983-9,

Lecturer, Snr Lecturer, Reader, HoD, Dept. Applied Geology, Strathclyde University 1969-1983,

Geologist (party chief), Falconbridge Nickel Mines, Canada 1965-1965,

British United Nations Association Geologist, Geological Survey, Solomon Islands 1963-1965

Works Chemist Improver, Howards of Ilford Limited, London, England 1958-1959

### Degrees

1973 Ph.D. Geochemistry/Ore geology – University of Durham, England

1963 B.Sc. Geology/Petrology (with 2 years organic chemistry) University of London

### All papers in the last 5 years

**Russell, M.J.** 2008, On the emergence and early evolution of life. *In* Life Strategies of Microorganisms in the Environment and in Host Organisms. F. Widdel (ed.) Halle, Nova Acta Leopoldina, in press.

**Russell, M.J.** 2008, A hydrothermal source of energy and materials at the origin of life. *In* "Chemical Evolution II: From Origins of Life to Modern Society". American Chemical Society, in press

**Russell, M.J.** 2008, The origin of life. *In* "Encyclopaedia of Geobiology". Singer, in press

**Russell, M.J.**, Allen, J.F., Milner-White, E.J. 2008, Inorganic complexes enabled the onset of life and oxygenic photosynthesis. *In* Energy from the Sun: 14th International Congress on Photosynthesis, J.F. Allen, E.Gantt, J.H. Golbeck, B. Osmond (editors). Springer. 1193-1198.

Milner-White, E.J., **Russell, M.J.**, 2008, Predicting peptide and protein conformations in early evolution. *Biology Direct* **3**, 3: doi:10.1186/1745-6150-3-3

**Russell, M.J.** 2007, The alkaline solution to the emergence of life: Energy, entropy and early evolution. *Acta Biotheoretica*, **55**, 133-179, Erratum at:- DOI 10.1007/s10441-007-9018-5

Martin, W., **Russell M.J.** 2007, On the origin of biochemistry at an alkaline hydrothermal vent. *Philosophical Transactions, Royal Society of London (Ser.B)* **362**, 1887-1925

Baaske, P., Weinert, F., Duhr, S., Lemke, K., **Russell, M.J.** & Braun, D. 2007, Extreme accumulation of nucleotides in simulated hydrothermal pore systems. *Proceeding National Academy Science, USA*, **104**, 9346-9351.

- Russell, M.J.** 2007, Der heiße Ursprung des Lebens. *Spektrum der Wissenschaft*, January 2007, 73-81.
- Russell, M.J.** 2006, First life. *American Scientist*, 94, 32-39. (invited paper)
- Russell, M.J.** & Hall, A.J., 2006, The onset and early evolution of life. *in* Kesler, S.E., and Ohmoto, H., eds., *Evolution of Early Earth's Atmosphere, Hydrosphere, and Biosphere—Constraints from Ore Deposits*, Geological Society of America, Memoir 198, p. 1-32, doi:10.1130/2006.1198(01). (Invited paper).
- Russell, M.J.**, Hall, A.J., Boyce, A.J., Fallick, & A.E., 2005, On hydrothermal convection systems and the emergence of life. *Economic Geology*, 100, 419-438 (Invited Centenary Paper).
- Milner-White, E.J. & **Russell, M.J.**, 2005, Sites for phosphates and iron-sulfur thiolates in the first membranes: 3 to 6 residue anion-binding motifs (nests): *Origins of Life and Evolution of the Biosphere*, 35, 19-27.
- Russell, M.J.** & Arndt, N.T., 2005. Geodynamic and metabolic cycles in the Hadean. *Biogeosciences*, 2, 97-111.
- Edwards, H.G.M., Moody, C.D., Newton, E.M., Villar, S.E.J., & **Russell, M.J.**, 2005, Raman spectroscopic analysis of cyanobacterial colonization of hydromagnesite, a putative martian extremophile. *Icarus*, 175, 372-381.
- Russell, M.J.** & Martin, W., 2004. The rocky roots of the acetyl coenzyme-A pathway. *Trends in Biochemical Science*, 24, 358-363.
- Russell, M.J.** 2003. On the importance of being alkaline. *Science* 302, 580-581.
- Martin, W. & **Russell, M.J.**, 2003, On the origin of cells: An hypothesis for the evolutionary transitions from abiotic geochemistry to chemoautotrophic prokaryotes, and from prokaryotes to nucleated cells. *Philosophical Transactions of the Royal Society of London* 358B, 27-85.
- Russell, M.J.**, 2003. Origin and evolution of life: clues from ore deposits. *Transactions of the Institution of Mining and Metallurgy* 112, B177-178.
- Russell, M.J.**, Hall, A.J. and Mellersh, A.R. 2003, On the dissipation of thermal and chemical energies on the early Earth: The onsets of hydrothermal convection, chemiosmosis, genetically regulated metabolism and oxygenic photosynthesis, in "Natural and Laboratory-Simulated Thermal Geochemical Processes" R. Ikan ed. Dordrecht, Kluwer Academic Publishers pp. 325-388.
- Russell, M.J.** 2003, How did life begin? *New Scientist*, 14th June, 33-34. (Invited).
- Boyce, A.J., Little, C.T.S. & **Russell, M.J.**, 2003, A new fossil vent biota in the Ballynoe barite deposit, Silvermines, Ireland: Evidence for intracratonic sea-floor hydrothermal activity about 352 Ma. *Economic Geology*, 98, 649-656.

### Ongoing collaborations

- A. Hall, J. Milner-White (University of Glasgow, UK) on early geochemistry, proteins and membranes.
- W. Martin, (University of Düsseldorf, Germany) on microbiological/metabolic pathways and early evolution.
- W. Nitschke, (Laboratoire de Bioénergétique et Ingénierie des Protéines (UPR 9036), CNRS, Marseille/France) on electron sinks and nitrogen oxide reduction.
- J.F. Allen (Biological & Chemical Sciences, Queen Mary, University of London, E1 4NS) on the origin of oxygenic photosynthesis.
- J.M. Garcia-Ruiz (University of Granada, Spain) on inorganic membranes;

### Invited lectures and lecture tours

2008 American Chemical Society, 235<sup>th</sup> meeting, Chemical Evolution, New Orleans

- 2008 Gordon Conference “Origin of Life” Ventura  
 2008 Bennett Lecture, University of Leicester 50<sup>th</sup> anniversary  
 2008 CosmoCaixa Science Museum in Barcelona “The Beautiful Story of the Cosmos”.  
 2007 **Plenary** Lecture, "Biosphere Origin and Evolution", Greece  
 2007 Invited lecture, 14<sup>th</sup> International congress of Photosynthesis, Glasgow, Scotland  
 2007 Invited lecture, Carnegie Institute, Washington  
 2007 Invited lecture, Johns Hopkins,  
 2007 Invited lecture, Emergence of life – Los Alamos  
 2007 Invited lecture, Origin of life and oxygenic photosynthesis, UC Berkley  
 2007 Invited lecture - RNA, the origin of life, and evolution, University of Kansas  
 2006 **Keynote** address, Goldschmidt Conference, Abiotic-biotic transition, Melbourne, Australia  
 2006 Invited lecture, Origin of life, Santa Fe Institute, USA  
 2006 Opening lecture, Lecture series – University of Bremen, Origin and Evolution of Life  
 2006 **Keynote** address, Life in the Universe, IMA, Kolbe, Japan  
 2006 Invited lectures, Origin of life, University of Uppsala, Stockholm  
 2006 Invited Lecture, Early Evolution, Leopoldina Symposium, Bremen, Germany  
 2006 Invited lectures, NORDITA Astrobiology, Kittila, Finland  
 2005 Invited lectures, Origin of life, Chemical Physics, Earth Science, Caltech  
 2005 **Opening** lecture, Origins and evolution of cells, Queen Mary College, London  
 2005 **Opening** Lecture, Astrobiology, NORDITA, Copenhagen  
 2005 **Keynote** address, Mineral Deposits Study Group, Ireland  
 2004 Invited lecture to Jet Propulsion Laboratory, Pasadena, USA  
 2004 Invited lectures, Astrobiology, UCL  
 2004 Invited lectures to ETH Zurich & LM University, Munich  
 2004 Invited lectures to CNRS Marseille, Grenoble & Paris Sud  
 2004 Invited lectures to Macquarie University Astrobiology & University of Tasmania  
 2004 **Opening** Lecture, Gordon Conference, Metals and Evolution, Maine, USA  
 2004 EGU, COSPAR, Paris, Hydrothermal Reactors and the Origin of Life  
 2003 Invited lectures, University of Arizona at Tempe and Tucson  
 2003 **Keynote** speaker, Fermor Conference, University of Wales  
 2003 British Association invited lecture  
 2002 Royal Society of Chemistry AGM invited lecture "Astrochemistry of life"  
 2002 The Kongsberg Seminar, Norway, invited lecture  
 2002 Invited lecture, University of Bergen  
 2001 Earth System Processes, GSA/GSL, Edinburgh, Convenor/speaker  
 2001 Invited lecture, Goldschmidt 2001, Mineral catalysts in organic synthesis, Virginia,  
 2001 British Association invited lecture  
 2001 Invited lecture ACS, Carbon dioxide in biogeochemistry, USA  
 2000 Invited Lecture, EMBO Symposium on Microbial Evolution.  
 2000 Convener/Lecturer, Goldschmidt Conference, Origin of Life, Oxford  
 1999 NASA Ames Research Center, Origin of Life/Exploring for Fossil Life on Mars.  
 1999 Invited lecture, Gordon Conference, Metals in Biology, Ventura, California.  
 1999 Invited Lecture, De La Beche Club, The Origin of Life.  
 1998 Invited lecture, GEOSCIENCE98, Life on other planets and the early Earth?  
 1998 Invited Lecture, Royal Astronomical Society, Planets outside the Solar System.  
 1998 Invited lecture, Life on Mars, British Interplanetary Society.  
 1997 **Keynote** Address, Giant Orebodies, Neves-Corvo Conference, University of Lisbon  
 1997 SEG-GSA Symposium, "Ore Deposits Through Time", Salt Lake City,  
 1996 International workshop, CIBA Evolution of hydrothermal ecosystems....  
 1996 **Keynote** Address, Thermophiles: University of Georgia, USA.  
 1995 Invited lecture, Open University Geological Society Meeting

- 1995 Invited lecture, University of Granada, Biomineral Patterns & Materials Science
- 1995 Lecturer, University of Granada Summer School on Origin of Life
- 1994 Invited lecture, British Association Meeting.
- 1994 **Keynote** address, 12th Australian Geological Congress.
- 1995 Invited lecture, Open University Geological Society Meeting
- 1995 Invited lecture, University of Granada, Biomineral Patterns & Materials Science
- 1995 Lecturer, University of Granada Summer School on Origin of Life
- 1993 Invited lecture tour, Universities in New Zealand.
- 1993 Invited lecture, Washington University, St. Louis, USA.
- 1992 Invited lecture, British Association Meeting.
- 1992 Invited lecture, Scientific Committee for Oceanographic Research, Sweden,
- 1992 Invited lectures, The Jagiellonian University, Krakow,
- 1991 Co-organiser and speaker, "The Inorganic-Organic Interface", Ross Priory, Scotland
- 1991 Invited lecture to Scientific Committee for Oceanographic Research, Oregon, USA.
- 1988 Invited lecturer, lead-zinc orebodies, University of Bilbao, Spain.
- 1988 **Review Lecture**, Economic Geology, Centennial meeting, Geological Society America.
- 1988 Invited Senior Scientist, Sept-Oct. University of Oslo.
- 1989 **Distinguished** Lecturer, Institution of Mining & Metallurgy.
- 1989 **Review** Seminar, Mineral Deposit Models. Geological Society, London.
- 1987 **Keynote** Speaker, Mineral Deposit Research in the UK. GSL.
- 1987 Invited participant, Gordon Conference on Hydrothermal Geochemistry 1990, USA
- 1986 Invited lecture, opening of Centre of Earth Resource Research, Memorial University, Newfoundland.
- 1986 Visiting Lecture tour of North America, Society of Economic Geologists.
- 1986 Invited lecturer, Economic Geology Section, Geological Society of America A.G.M.
- 1986 **Principal** Lecturer, Institution of Geologists - A.G.M.
- 1986 **Closing** Address, VII International Association on the Genesis of Ore Deposits, Luleå, Sweden.
- 1984 Invited lecturer, 31st Inter Universities Geological Congress.
- 1983 Geological Association of Canada Short Course Lecturer,
- 1981 **"Prominent Geologist's"** Lecturer to Atlantic Geoscience Society of Canada and Lecture tour of the Maritime Provinces.
- 1980 Australian Academy of Sciences Lecturing Fund. A.N.U., C.S.I.R.O. Sydney, Adelaide, Townsville, Tasmania.
- 1980 **Keynote** Speaker, 4th Australian Geological Convention.
- 1977 **Royal Norwegian Foreign Office Guest Lecturer**, Universities in Norway.
- 1973 Invited lecturer, First Symposium, Metallogenesis & Plate Tectonics, Newfoundland.
- 1972 Invited lecturer, First Symposium on Implications of Continental Drift, Newcastle.

### **Full publication list**

#### Refereed papers in international journals and memoirs

- Russell, M.J. 2007, On the emergence and early evolution of life. In *Life Strategies of Microorganisms in the Environment and in Host Organisms*. F. Widdel (ed.) Halle, Nova Acta Leopoldina, in press.
- Russell, M.J., Allen, J.F., & Milner-White, E.J. 2008, Inorganic complexes enabled the onset of life and oxygenic photosynthesis. In *Energy from the Sun: 14th International Congress on Photosynthesis*, J.F. Allen, E.Gantt, J.H. Golbeck, B. Osmond (editors). Springer. 1193-1198.
- Milner-White, E.J., & Russell, M.J., 2008, Predicting peptide and protein conformations in early evolution. *Biology Direct* **3**, 3: doi:10.1186/1745-6150-3-3

- Russell, M.J. 2007, The alkaline solution to the emergence of life: Energy, entropy and early evolution. *Acta Biotheoretica*, 55, 133-179. Erratum at:- DOI 10.1007/s10441-007-9018-5
- Martin, W., & Russell M.J. 2007, On the origin of biochemistry at an alkaline hydrothermal vent. *Philosophical Transactions, Royal Society of London (Ser.B)* 362, 1887-1925
- Baaske, P., Weinert, F., Duhr, S., Lemke, K., Russell, M.J. & Braun, D. 2007, Extreme accumulation of nucleotides in simulated hydrothermal pore systems. *Proceeding National Academy Science, USA*, 104, 9346-9351.
- Russell, M.J. 2007, Der heiße Ursprung des Lebens. *Spektrum der Wissenschaft* January 2007, 73-81.
- Russell, M.J. 2007, The alkaline solution to the emergence of life: Energy, entropy and early evolution. *Acta Biotheoretica*, in press.
- Baaske P., Weinert, F., Duhr, S., Lemke, K., Russell, M.J. & Braun, D. 2007, Extreme accumulation of nucleotides in simulated hydrothermal pore systems. *Proceeding National Academy Science, USA*, 104, 9346-9351.
- Martin, W., Russell M.J. 2007, On the origin of biochemistry at an alkaline hydrothermal vent. *Philosophical Transactions, Royal Society of London (Ser.B)* DOI 10.1098/rstb.2002.1183.
- Russell, M.J. 2007, Der heiße Ursprung des Lebens. *Spektrum der Wissenschaft*, January 2007, 73-81.
- Russell, M.J. & Hall, A.J., 2006, The onset and early evolution of life. in Kesler, S.E., and Ohmoto, H., eds., Evolution of Early Earth's Atmosphere, Hydrosphere, and Biosphere—Constraints from Ore Deposits, *Geological Society of America, Memoir* 198, p. 1-32, doi:10.1130/2006.1198(01). (Invited paper).
- Russell, M.J. 2006, First life. *American Scientist*, 94, 32-39.
- Milner-White, E.J., and Russell, M.J., 2005, Sites for phosphates and iron-sulfur thiolates in the first membranes: 3 to 6 residue anion-binding motifs (nests): *Origins of Life and Evolution of the Biosphere*, v. 35, 19-27.
- Russell, M.J., Hall, A.J., Fallick, A.E., Boyce, A.J., 2005, On hydrothermal convection systems and the emergence of life. *Economic Geology*, **100**, 419-438.
- Russell, M.J. and Arndt, N.T., 2005. Geodynamic and metabolic cycles in the Hadean. *Biogeosciences*, v. **2**, p. 97-111.
- Russell, M.J., and Martin, W., 2004. The rocky roots of the acetyl coenzyme-A pathway. *Trends in Biochemical Science*, 24, 358-363.
- Martin, W. & Russell, M.J. 2003, On the origin of cells: An hypothesis for the evolutionary transitions from abiotic geochemistry to chemoautotrophic prokaryotes, and from prokaryotes to nucleated cells. *Philosophical Transactions of the Royal Society of London* 358B, 27-85.
- Russell, M.J. 2003. On the importance of being alkaline. *Science* 302, 580-581.
- Russell, M.J. 2003. Origin and evolution of life: clues from ore deposits. *Trans. Inst. Min. Metall.* 112, B177-178.
- Boyce, A.J., Little, C.T.S. & Russell, M.J. 2003, A new fossil vent biota in the Ballynoe barite deposit, Silvermines, Ireland: Evidence for intracratonic sea-floor hydrothermal activity about 352 Ma. *Economic Geology*, 98, 649-656.
- Blakeman, R.J., Ashton, J.H., Boyce, A.J., Fallick, A.E. & Russell, M.J. 2002, Timing of interplay between hydrothermal and surface fluids in the Navan Zn+Pb deposit, Ireland: Evidence from metal distribution trends, mineral textures and <sup>34</sup>S analyses. *Economic Geology*, 97, 73-91.
- Russell, M.J. & Hall, A.J. 2002, From geochemistry to biochemistry: chemiosmotic coupling and transition element clusters in the onset of life and photosynthesis. *The Geochemical News* no. 113/October: 6-12.
- Fallick, A.E., Ashton, J.H., Boyce, A.J., Ellam, R.M. & Russell, M.J. 2001, Bacteria were responsible for the magnitude of the world-class hydrothermal base-metal orebody at Navan, Ireland. *Economic Geology*, 96, 885-890.

- Zedef, V., Russell, M.J., Hall, A.J. and Fallick, A.E., 2000. Genesis of Vein-Stockwork and Sedimentary Magnesite and Hydromagnesite Deposits in the Ultramafic Terranes of Southwestern Turkey: A Stable Isotope Study. *Economic Geology*, **95**, 429-446.
- Russell, M.J., Ingham, J.K., Zedef, V., Maktav, D., Sunar, F., Hall, A.J. & Fallick, A.E. 1999. Search for signs of ancient life on Mars: Expectations from hydromagnesite microbialites, Salda Lake, Turkey. *J.Geol.Soc.Lond.*, **156**, 869-888.
- Anderson, I.K., Ashton, J.H., Boyce, A.J., Fallick, A.E. & Russell, M.J. 1998, Ore depositional processes in the Navan Zn+Pb deposit, Ireland. *Economic Geology*, **93**, 535-563.
- Russell, M.J. & Hall, A.J. 1997, The emergence of life from iron monosulphide bubbles at a submarine hydrothermal redox and pH front. *J.Geol.Soc.Lond.*, **154**, 377-402.
- Duller, P.R., Gallagher, M.J., Hall, A.J. & Russell, M.J. 1997. Glendinning deposit - an example of turbidite-hosted arsenic-antimony-gold mineralization in the Southern uplands, Scotland. *Trans. Instn Min. Metall.* **106**, 118-133.
- Russell, M.J., 1996. The generation at hot springs of ores, microbialites and life. *Ore Geology Reviews*, **10**, 199-214.
- Smythe, D.K., Russell, M.J. & Skuse, A.G. 1995. Intra-continental rifting inferred from the major late Carboniferous quartz-dolerite dyke swarm of NW Europe. *Scott. J. Geol.*, **31**, 151-162.
- Lewis, H., Couples, G.D. & Russell, M.J. 1995. Characterization of fluid-flow systems for Irish lead-zinc deposits — contributions from mass balance. *Trans. Instn Min. Metal. (Sect. B: Appl. earth sci.)* **104**, B145-155.
- Macleod, G., Mckeown, C., Hall, A.J. & Russell, M.J. 1994. Hydrothermal and oceanic pH conditions at 4Ga relevant to the origin of life. *Origins of life and evolution of the Biosphere*. **24**, 19-41.
- Kaschke, M., Russell, M.J. & Cole, W.J. 1994 [FeS/FeS<sub>2</sub>]. A redox system for the origin of life. *Origins of life and evolution of the Biosphere* **24**, 43-56.
- Cole, J.W., Kaschke, M., Sherringham, J., Curry, G.B., Turner, D. & Russell, M.J. 1994. Can amino acids be synthesised by H<sub>2</sub>S in anoxic lakes? *Marine Chemistry* **45**, 243-256.
- Russell, M.J., Daniel, R.M., Hall, A.J. & Sherringham, J. 1994. A hydrothermally precipitated catalytic iron sulphide membrane as a first step toward life. *Journal of Molecular Evolution* **39**, 231-243
- Russell, M.J., Daniel, R.M. & Hall, A.J. 1993. On the emergence of life via catalytic iron sulphide membranes. *Terra Nova* **5**, 343-347.
- Banks, D.A. & Russell, M.J. 1992. Fluid mixing during ore deposition at the Tynagh base-metal deposit, Ireland. *European Journal of Mineralogy*, **4**, 921-931.
- Cairns-Smith, A.G., Hall, A.J. & Russell, M.J. 1992. Mineral theories of the origin of life and an iron sulphide example. *Origins of life and evolution of the Biosphere*, **22**, 161-180.
- Mohamad, D.B., Mackenzie, A.B., Stephens, W.E. & Russell, M.J. 1992 Exploration methods for nuclear waste repositories or mineral deposits---from source to sink, where's the front? *Trans. Instn Min. Metall. (Sect. B: Appl. earth sci.)*, **101**,139-146.
- Russell, M.J. & Skauli, H. 1991. A history of theoretical developments in carbonate-hosted base metal deposits and a new tri-level enthalpy classification. *Economic Geology: Monograph*. **8**, 96-116.
- Fallick, A.E. Ilich, M. & Russell, M.J. 1991. A stable isotope study of the magnesite deposits associated with the Alpine-type ultramafic rocks of Yugoslavia. *Economic Geology*, **86**, 847-861.
- Russell, M.J., Hall, A.J., & Gize, A.P. 1990. Pyrite and the origin of life. *Nature* **344**, 387.
- Brydie, J.R., Fallick, A.E., Ilich, M., Maliotis, G. & Russell, M.J. 1993 Stable isotope study of magnesite deposits in Akamas area, northwest Cyprus. *Trans. Instn Min. Metal. (Sect. B: Appl. earth sci.)* **102**, 50-53.
- Patrick, R.A.D., & Russell, M.J. 1989. Sulphur isotopic investigation of Lower Carboniferous vein deposits of the British Isles. *Mineralium Deposita*, **24**, p.148-153.

- Anderson, I.K., Andrew, C.J., Ashton, J.H., Boyce, A.J., Caulfield, J.B.D. Fallick, A.E. & Russell, M.J. 1989. Preliminary sulphur isotope data of diagenetic and vein sulphides in the Lower Palaeozoic strata of Ireland and Southern Scotland: implications for Zn+Pb+Ba mineralization. *Journal of the Geological Society of London*, **146**, 715-720.
- Russell, M.J., Hall, A.J., & Turner, D. 1989. In vitro growth of iron sulphide chimneys: possible culture chambers for origin-of-life experiments. *Terra Nova*, **1**, p.238-241.
- Russell, M.J. & Hall, J. 1988. Mechanics of downward permeation of water in crystalline rock, with application to problems of geothermal energy extraction. *Trans. Inst. Min. Metall. (Appl. Earth Sci.: sect B)*, **97**, p.B51-56.
- Russell, M.J., Hall, A.J., Cairns-Smith, A.G., and Braterman, P.S. 1988. Submarine hot springs and the origin of life, *Nature*, **336**, p.117.
- Hays, S.J., Hall, G., Simmons, J., & Russell, M.J. 1988. Sealed microcracks in the Lewisian of NW Scotland: a record of 2 billion years of fluid circulation. *Geol. Soc. London*, **145**, p.145, p.819-830.
- Mills, H., Halliday, A.N., Ashton, J.H., Anderson, I.K. & Russell, M.J. 1987. Origin of a giant orebody at Navan, Ireland. *Nature*, **327**, 223-225.
- Samson, I.M. & Russell, M.J. 1987. Genesis of the Silvermines zinc-lead-barite deposit, Ireland: fluid inclusion and stable isotope evidence. *Econ. Geol.*, **82**, 371-394.
- Russell, M.J., Allison, I. Anderton, R. & Hall, A.J. 1986. Metamorphic Limestones of the Great Glen Area: Comments. *Scott. J. Geol.*, **22**, 137-139.
- Russell, M.J. 1986. Search and research for Britain's Geological Resources. *British Geologist*, **12/2**. 50-51.
- Russell, M.J. & Allison, I. 1985. Agalmatolite and the maturity of sandstones of the Appin and Argyll groups and Eriboll sandstone. *Scott. J. Geol.*, **21**, 513-545.
- Allison, I. & Russell, M.J. 1985. Anhydrite discovered in the Fucoid Beds of Northwest Scotland. *J. Sedimentary Research*, **55**, 917-918.
- Russell, M.J. 1985. The evolution of the Scottish Mineral sub-province, *Scott. J. Geol.*, **21**, 513-545.
- Russell, M.J. 1985. Comment on 'Ore genesis by episodic dewatering of sedimentary basins: application to giant Proterozoic lead-zinc deposits' by F. J. Sawkins. *Geology*, **13**, 318.
- Russell, M.J. & Smythe, D.K. 1983. On the origin of the Oslo Graben in relation to the Hercynian-Alleghenian Orogeny and Lithospheric rifting in the North Atlantic. *Tectonophysics*, **94**, 457-472.
- Boyce, A.J., Anderton, R. & Russell, M.J. 1983. Rapid subsidence and Early Carboniferous base-metal mineralization in Ireland. *Trans. Instn Min. Metall, (Appl. Earth Sci.: sect B)*, **92**, B55-66.
- Jassim, R.Z., Patrick, R.A.D. & Russell, M.J. 1983. On the origin of the silver+copper+cobalt+baryte mineralization of the Ochil Hills, Scotland: a sulphur isotope study. *Trans. Instn Min. Metall.(Appl. Earth Sci.: sect B)*, **92**, B213-216.
- Patrick, R.A.D., Coleman, M.L. & Russell, M.J. 1983. Sulphur isotopic investigation of vein lead-zinc mineralization at Tyndrum, Scotland. *Mineralium Deposita*, **18**, 477-485.
- Russell, M.J. 1983. Major sediment-hosted zinc + lead deposits: formation from hydrothermal convection cells that deepen during crustal extension. *Short Course in sediment-hosted stratiform lead-zinc deposits*. Mineralogical Association of Canada, Short Course Handbook, vol. **8**, 251-282.
- Boyce, A.J., Coleman, M.L. & Russell, M.J. 1983. Formation of fossil hydrothermal chimneys and mounds from Silvermines, Ireland. *Nature*, **306**, 545-550.
- Russell, M.J., Solomon, M. & Walshe, J.L. 1981. The genesis of sediment-hosted, exhalative zinc + lead desposits. *Mineralium Deposita*, **16**, 113-127.
- Larter, R.C.L., Boyce, A.J. & Russell, M.J. 1981. Hydrothermal pyrite chimneys from the Ballynoe Baryte deposit, Silvermines, County Tipperary, Ireland. *Mineralium Deposita*, **16**, 309-318.

- Russell, M.J., Solomon, M. & Walshe, J.L. 1981. Mechanisms of sulphide deposition in sediment-hosted exhalative lead+zinc deposits. *Bureau of Mineral Resources, Journal of Geology and Geophysics*, **6**, 329-330.
- Samson, I.M. & Russell, M.J. 1981. Fluid inclusion data from the Silvermines Zn+Pb+BaSO<sub>4</sub> deposits, Ireland: a preliminary note. *Trans. Instn Min. Metall., (Appl. Earth Sci.: sect B)*, **92**, B67-71.
- Russell, M.J. 1978. Downward-excavating hydrothermal cells and Irish-type ore deposits: importance of an underlying thick Caledonian Prism. *Trans. Instn Min. Metall., (Appl. Earth Sci.: sect B)*, **89**, B168-171.
- Smythe, D.K., Kenolty, N. & Russell, M.J. 1978. Seismic evidence for Mesozoic sedimentary troughs on the Hebridean continental margin. *Nature*, **276**, 420.
- Russell, M.J. 1976. A possible Lower Permian age for the onset of ocean floor spreading in the northern North Atlantic. *Scott. J. Geol.*, **12**, 315-323.
- Russell, M.J. 1975. Lithogeochemical environment of the Tynagh base-metal deposit, Ireland, and its bearing on ore deposition. *Trans. Instn Min. Metall., (Appl. Earth Sci.: sect B)*, **84**, B128-133.
- Russell, M.J. 1974. Manganese halo surrounding the Tynagh ore deposit, Ireland: a preliminary note. *Trans. Instn Min. Metall., (Appl. Earth Sci.: sect B)*, **83**, B65-66.
- Russell, M.J. 1972. North-south geofractures in Scotland and Ireland. *Scott. J. Geol.*, **8**, 75-84.
- Russell, M.J. 1972. Base-metal prospecting in Scotland - theory and method. *Proc. Soc. Analyt. Chem.*, **9**, 154-6.
- Russell, M.J. & Burgess, A.S. 1969. Tectonic comparison of North Atlantic and Middle East Rifting. *Nature*, **222**, 1056-7.
- Russell, M.J. 1968. Structural controls of base-metal mineralization in Ireland in relation to continental drift. *Trans. Instn Min. Metall., (Appl. Earth Sci.: sect B)*, **B77**, 117-28, **B78**, 127-131.

#### Refereed book chapters

- Russell, M.J., Hall, A.J. and Mellersh, A.R. 2003, On the dissipation of thermal and chemical energies on the early Earth: The onsets of hydrothermal convection, chemiosmosis, genetically regulated metabolism and oxygenic photosynthesis, in "Natural and Laboratory-Simulated Thermal Geochemical Processes" R. Ikan ed. Dordrecht, Kluwer Academic Publishers pp. 325-388.
- Russell, M.J. & Hall, A.J. 1999. On the inevitable emergence of life on Mars. In: J.A. Hiscox (ed) *Proc. 1<sup>st</sup> UK Conference Search for Life on Mars*. British Interplanetary Society, 26-36.
- Russell, M.J., Daia, D.E. & Hall, A.J. 1998. The emergence of life from FeS bubbles at alkaline hot springs in an acid ocean. In: *Thermophiles: The keys to molecular evolution and the origin of life?* J. Wiegel & M.W. Adams, eds, Taylor and Francis, London and Philadelphia, 77-126.
- Russell, M.J., Couples, G.D. & Lewis, H. 1995. SEDEX genesis and super-deep boreholes: Can hydrostatic pressures exist down to the brittle-ductile boundary? In: *Mineral deposits: From their origin to their environmental impact*. J. Pasava B., Kribek & K. Zak eds, A.A. Balkema, Rotterdam, pp 315-318.
- Russell, M.J. & Hall, A.J. 1995. The emergence of life at hot springs: A basis for understanding the relationships between organics and mineral deposits. In: *Mineral deposits: From their origin to their environmental impact*. J. Pasava, B. Kribek & K. Zak eds, Balkema, Rotterdam, 793-796.
- Boyce, A.J., Fletcher, T.J., Fallick, A.E., Ashton, J. & Russell, M.J. 1993. Petrographic and <sup>34</sup>S study of lower Palaeozoic rocks under the Navan Zn+Pb deposits. In: *Current Research in Geology Applied to Ore Deposits*, P. Fenoll et al. eds, Proc. 2<sup>nd</sup> Biennial SGA Meeting, Granada, 53-56.



- Russell, M.J. and Haszeldine, R.S. 1992. Accounting for geofractures. In: *The Irish Minerals Industry - 1980-1990*. A.A. Bowden, G. Earls, P.G. O'Connor & J.F. Pyne (editors). Irish Association of Economic Geologists, Dublin, 135-142.
- Russell, M.J. 1992. Plate tectonics and hydrothermal ore deposits. In: *Understanding the Earth* (2nd Ed.). C.G. Brown, C.J. Hawkesworth & R.C.L. Wilson (editors). Cambridge University Press. 204-221.
- Russell, M.J. 1988. A model for the genesis of sediment-hosted exhalative (SEDEX) ore deposits. *Proc. Seventh IAGOD Symposium*. Zachrisson, E. ed., Schweizerbartsche Verlagsbuch handlung, p. 59-66.
- Russell, M.J. 1988. Chimneys, chemical gardens and feldspar horizons+pyrrhotine in some SEDEX deposits: aspects of alkaline environments of deposition. *Proc. seventh IAGOD Symposium*. Zachrisson, E. ed., Schweizerbartsche Verlagsbuch handlung, p.183-190.
- Haszeldine, R.S. and Russell, M.J. 1987. The Late Carboniferous northern North Atlantic Ocean: implications for hydrocarbon exploration from Britain to the Artic. In: *Petroleum Geology of North West Europe*. Graham and Trotman, p.1163-1175.
- Russell, M.J. 1986. Extension and convection: a genetic model for the Irish Carboniferous base metal and barite deposits. In: *Geology and Genesis of Mineral Deposits in Ireland*, eds. C.J. Andrew, et al. Irish Association for Economic Geology, 545-554.
- Russell, M.J. 1986. Reflections on the genesis of the Irish Carboniferous lead + zinc + baryte deposits. In: *Geology in the Real World - the Kingsley Dunham Volume*, eds. R.W. Nesbitt and I. Nichol. Institution of Mining and Metallurgy, 375-386.
- Russell, M.J., Hall, A.J., Willan, R.C.R., Allison, I., Anderton, R. & Bowes, G. 1984. On the origin of the Aberfeldy celsian+baryte+base metal deposit, Scotland. In: *Prospecting in Areas of Glaciated Terrain*. Institution of Mining and Metallurgy, 159-170.
- Gray, G.J. and Russell, M.J. 1984. Regional Mn-Fe lithogeochemistry of the Lower Carboniferous Waulsortian 'Reef' Limestone in Ireland. In: *Prospecting in Areas of Glaciated Terrain*, Institution of Mining and Metallurgy, 57-68.
- Russell, M.J., Boyce, A.J., Larter, R.C.L. & Samson, I.M. 1982. The significance of hydrothermal pyrite chimneys in the Silvermines Deposit. In: *The origins of the Irish lead-zinc deposits*. eds. Brown, A. Irish Association for Economic Geology, 171-172.
- Russell, M.J. 1979. Geofracture controls of Mississippian base-metal mineralization in Ireland, Scotland and Wales. In: *Proceedings of the Second International Conference on Basement Tectonics*. eds. Podwysocki, M.H. and Earle, J.L. Basement Tectonics Committee Inc. 445-450.
- Russell, M.J. and Smythe, D.K. 1978. Evidence for an early Permian oceanic rift in the northern North Atlantic. In: *Petrology and Geochemistry of Continental Rifts*. eds. Neumann, E-R, and Ramberg, I.B. Reidel Publishing Co. 173-179.
- Russell, M.J. 1978. Mineralization in a fractured craton. In: *Crustal Evolution in Northwestern Britain and Adjacent Region.*, eds. Bowes, D.R. and Leake, B.E. Geological Journal Special Issue No.10, 297-308.
- Russell, M.J. 1976. Incipient plate separation and possible related mineralization in lands bordering the North Atlantic. In: *Metallogeny and Plate Tectonics*, ed. Strong, D.F. *Geological Association of Canada, Special paper* **14**, 339-349.
- Russell, M.J. 1973. Base-metal mineralization in Ireland and Scotland and the formation of Rockall Trough. In: *Implications of Continental Drift to the Earth Sciences*, eds. Tarling, D H and Runcorn, S.K. Academic Press, London, vol. **1**, 581-597.

#### Articles

- Russell, M.J. 2003, How did life begin? *New Scientist*, 14th June, 33-34.
- Russell, M.J. 1996. Life from the depths. *Science Spectra*, **1**, no. 4, 26-31.
- Russell, M.J. 1995. Hot water and the emergence of life. *Open University Geological society Journal*. **16**, no. 2, 9-11.

- Russell, M.J. 1993. The origin of minerals and life at hot springs. *Annual Review 1993 Irish Association for Economic Geology*. 20-23.
- Russell, M.J. 1992 Mining, metallurgy and the origin of life. *Minerals Industry International/IMM Bull* no. **1009**, 4-8
- Russell, M.J. 1974. Metals and oil flow between developing and developed countries. IN: *The Third World*, eds. Stirling, and Kelley, E. 6-11.
- Russell, M.J. and Jantaranipa, W. 1974. Geochemical indications of an ancient lead smelter site at Eccles near Thornhill. *Trans. J. Proc. Dumfries and Galloway Nat. Hist. Antiq. S.*, **49**, 7-11.
- Russell, M.J. 1972. World mineral resources, prospects for the future. *Universitas*, **2**, 80-101.

### Grants

- £142,157 NERC -GR3/09926 Origin of life (1996-1999) Final report rated excellent
- £2,000 Gresham College, Exobiology 1997-8.
- £159,176 NERC -GR3/7779, Origin of life (1992-1995) Final report rated very good
- £35,000 NERC/Riofinex Industrial Partnership Scheme, (1992-1995).
- £1,000 RTZ Technical Services, Grant for fieldwork and conference in the Iberian Pyrite Belt, 1997.
- £139,000 NERC (with Dr Fallick PI, SURRC) - S isotope analyses of ores (1986-1991) Final report rated excellent
- £14,600 Britoil (with Dr R.S. Haszeldine) - reservoir fluid inclusion (1986)
- £3,000 Exxon for technical support (1988).
- £35,000 Natural Environment Research Council /Riofinex Industrial Partnership Scheme, Structural Controls of SEDEX ore deposits in Ireland. (1992-1995)
- £3,994 Natural Environment Research Council - fluid inclusion research (1.10.78 - 29.4.84)
- £48,000 RioFinEx (with Dr A.J. Hall) - Dalradian Mineralization in Scotland (1982-1983)

### Outreach

- 2007 Discussions with Kansas teachers on teaching and evolution
- 1992-2006 Lectures to Edinburgh School of Art
- 2003 New Scientist
- 2001 BBC HORIZON. Life on Mars
- 1997 ITV Icon
- 1996 Radio Scotland, Ores in Scotland
- 1996 BBC 'Science Now', Origin of Life
- 1996 BBC 5, Night Moves
- 1996 BBC Scotland, The Usual Suspects
- 1995 Radio Scotland, The Oceans
- 1994 Radio Scotland, Origin of Mineral Deposits
- 1993 BBC HORIZON, on the Origin of Life
- 1993 Austrian TV, Origin of Life
- 1988 Radio Scotland debate with Prof Thomas Gold on The Deep Gas Hypothesis
- 1975 BBC News. Nuclear waste disposal
- Also, Open University Tutor, Lectures to amateur societies and young people's societies in Scotland, Numerous interviews with BBC and other radio stations

### Main external committee and board membership

- 2001-present Editorial Board of Astrobiology
- 1999 British National Space Centre - Panel Member: Exobiology, Extremophiles and Habitats
- 1992 Chairman, the NERC Review Committee, MSc Courses in Engineering Geology
- 1992 Chairman, the NERC Review Committee, Extractive Industries Partnership Scheme

1988-1992	Geological Sciences Research Grants & Training Awards Committee, the NERC
1988-present	Professional Affairs Committee, Institution of Mining & Metallurgy
1988-1995	Editorial Board of the Institution of Mining & Metallurgy
1988-1989	Chairman. Scottish Branch of the Institution of Mining & Metallurgy
1982-1983	Scottish Universities Council on Entrance: Working Party on Geology
1974-1980	Editorial Board of the Institution of Mining & Metallurgy

### **Teaching**

Geochemistry, Metallogenesis, Plate tectonics, Controversies in geology, Origin of Life, Geochemical exploration, Economic geology field course, Mineral exploration fieldwork,

### **PhD supervision (since 1990) (all successful)**

1988-1991	K Anderson (NERC) Genesis of the Giant Orebody at Navan, Ireland
1990-1993	Daud Mohamad, Simulation of radionuclide waste disposal
1990-1994	Veysel Zedef, Genesis of Turkish magnesite- stable isotopes
1992-1995	Helen Lewis, (NERC/Rio Tinto) Structural controls of Irish mineral deposits
1992-1996	C Ford, (NERC Case) Origin of the conglomerate goup ore, Navan, Ireland
1997 -2001	Rob Blakeman (NERC Case) Compositions and routes of fluids generating the Navan giant base-metal orebody
1998 -2003	Laiq Rahman, (NERC) Geochemistry of Emergent Life (with Dr Allan Hall)

### **Professional societies**

1963	Geological Society of London
1965	Institution of Mining and Metallurgy
1969	Geological Society of Glasgow
1975	Society of Economic Geologists
1984	Institution of Geologists
1995	International Society for the Study of the Origin of Life

### **Experience on instrumentation**

X-ray fluorescence; X-ray diffraction and mass spectrometry; Atomic Absorption Spectrophotometry; Magnetometry; Thermometric (fluid inclusion) analysis; Gravimetrics: Electron Microprobe; Scanning Electron Microscope

### **Departmental administration**

Setting up and development of the Applied Geology Department's Geochemical Laboratories at Strathclyde University. Running of 3rd and 4th year field excursion. Head of Department 1982-1989, Research co-ordinator from 1990-92, Research advisor 1993-95.

### **University administration**

Faculty Resource Committee, 1986-89
Faculty Review Panel, 1986-89
Chairman - Faculty Examination Board 1987-1989.
Senate Review Panel, 1986-89
Senate Member (ex officio from 1982)
Faculty Board (ex officio from 1982)
Faculty Planning Committee (elected member 1982-96)
Head of Department's Committee for Isotope Geology Unit (SURRC) 1981-1989
School Board (1969-72)

### **Conference organization**

Mediation across the abiotic-biotic transition at the dawn of life, Goldschmidt Conference, (Conveners, Michael Russell and Everett Shock) University of Melbourne, September 2006

Geochemistry and the origin of life, Goldschmidt Conference, (Conveners, Michael Russell and Everett Shock) University of Oxford, September 2000

The inorganic-organic interface - geological, chemical and biological prospects. 7-10th May 1991 with Drs. A.P. Gize and Dr S. Mann, Glasgow.

Genesis of and exploration for industrial and ore minerals Mineral Deposits Studies Group, 19 -21 December 1985, University of Strathclyde.

Prospecting in areas of glaciated terrain, 16 -18 May 1984.

University of Strathclyde & Institution of Mining and Metallurgy.

Origin of sediment-hosted stratiform metalliferous ores Mineral Deposits Study Group. 24 September 1982, Glasgow.

Caledonian Stratiform Sulphides, 25 April - 2 May 1981 University of Strathclyde.

Chemistry teachers induction course, organizer and lecturer (Mineral Industry Manpower and Careers Unit), 4 - 9 May 1981, University of Strathclyde.

### **Research and management skills**

Research funded by the Natural Environmental Research Council (UK) gained "excellent" ratings as PI or co-PI in final grant reports on "The Origin of Life", and "Isotope Studies of Ore Deposits". As Professor and Head of the Department of Applied Geology at the University of Strathclyde my department gained the highest rating in 1988 for research and teaching from the University Grants Committee of Great Britain.

Also, based on wide professional experience I have shown in over ninety publications that I can synthesize knowledge across most fields of science into coherent theory. Practical experience as a works chemist improver in the chemical industry (Howards of Ilford, London) gave me an understanding of the behaviour of metal catalysts in organic reactions prior to my University education. After my first degree, geochemical and geophysical surveying for the mining industry imparted knowledge of the wider properties of metal sulfides (Canada and Ireland). From geological surveying (Solomon Islands, Africa, UK) I gained experience in volcanology, field mapping, hydrothermal springs and hydrology. As an academic I have expertise in geochemical, isotopic (including GC-MS) and mineralogical analysis. I have also developed skills in chemical synthesis, and researched geothermal energy. More recently I have gained some expertise in biochemistry and microbiology from several international collaborations. All these experiences have been integrated into an evolutionary narrative that has culminated in an original theory for the emergence and early evolution of life which involves feedbacks between global tectonics, fluid flow, geochemistry, biochemistry and energetics.

### **Evidence of impact on, and major contributions to, the origin of life**

The Geological Society of America invited an update our theory for publication in a Special Issue concerned with the Early Earth (Russell and Hall, 2006). Our invited contribution to the Centenary Edition of Economic Geology has just been published (Russell et al., 2005).

An invitation from the Royal Society of London resulted in a paper written with my collaborator, Professor William Martin that explains the origins of cells through evolutionary transitions from abiotic geochemistry to chemoautotrophic prokaryotes, the early divergence of the prokaryotes into the eubacteria and the archaeobacteria, and the endosymbiotic event that produced the third domain of life, the eukaryotes (Martin and Russell, 2003). More than twenty other papers on the origin of life have been published since 1988. I have published three papers on the emergence and possible detection of life on Mars.

I have given over 60 invited lectures at international venues including 20 keynote lectures. Over 40 of these various invitations have centered on the Origin of Life and Astrobiology. They contribute

to the growing realization that "it is the inorganic elements that bring organic chemistry to life."

I have also been featured on two BBC HORIZON programmes on the Origin of Life and Life on Mars as well as on numerous other channels, radio programmes and in the press.

Because the hydrothermal origin of life is a "geological, geochemical and tectonic issue", my career in retrospect can be seen as leading to this field of research. Contributions at stages in development were:-

i) In a paper published in 1968 predicting the location of the giant zinc-lead orebody at Navan (discovered in 1971) I was first to place the large hydrothermal base-metal deposits in Ireland in a plate tectonic context. This paper was awarded the Arthur Claudet Students Prize 1968, from Institution of Mining & Metallurgy and was reproduced in a Benchmark Volume (1974). A letter on the topic was published in Nature, 1969 and invited papers were delivered to, and written for, the first symposia on Plate Tectonics and the Earth Sciences)

ii) Publication of the first extensive lithochemical manganese aureole around the Tynagh orebody, Ireland, proved a relationship with submarine springs in Carboniferous times (1973/4 in the Institution of Mining and Metallurgy (IMM)).

iii) An original theory explaining the genesis of giant base-metal deposits by downward excavating hydrothermal cells of moderate temperature was found to have general application (1978, 1981 et seq. IMM, Economic Geology etc.) and provided the physical basis for our theory on the onset of life.

iv) Lead isotopes were used to test the downward excavating-cell hypothesis. The hypothesis survived and alternative hypotheses were refuted (published in Nature 1987 and Economic Geology etc.).

v) Sulfur isotope analyses were used to test the sedimentary exhalative/diagenetic theories for the origin of the Irish orebodies. Again the theory passed the tests and afforded a deeper understanding of these world-class deposits (Nature 1983, Economic Geology etc.).

vi) Plate tectonic considerations led to the discovery of a giant 300 million year old dyke swarm in the North Sea, with intimations regarding petroleum resources in the western approaches to the British Isles (1980s) (1983 et seq., Tectonophysics etc.).

vii) The recognition of a Precambrian period of alkaline weathering could explain giant potassium and barium feldspar resources (1985 et seq. Sedimentology etc.).

viii) A new theory was developed to explain the origin of the Alpine magnesite deposits from alkaline hydrothermal solutions and tested with stable isotopes (1991, et seq. Economic Geology)

ix) I and my PhD students discovered the first fossil hydrothermal chimneys at Silvermines, Ireland, in 1980 (Nature, 1983). Later my students were the first to discover fossil hydrothermal polychaete worms (Nature 1985, Economic Geology).

### **Research developments**

My research has opened up a variety of fresh trans-disciplinary channels, some of which I continue to be involved with as a collaborator. Apart from predicting the discovery of alkaline hydrothermal vents on the ocean floor away from the ridges i.e., the Lost City vents, Kelley et al, 2001) my general model has been taken as a basis to explain:

i) the origins of RNA world (Braun and Libchaber, 2004; Koonin and Martin, 2005),

ii) the origin of metalloenzymes and the origin of the water oxidizing center in oxygenic photosynthesis (Fontecilla-Camps and Ragsdale, 1999; Rickard et al. 2001; Sauer and Yachandra, 2002; Baymann et al., 2003),

iii) The development of inorganic membranes and polymerization in hydrogen and other reactors (Matsumo, 1997; Stone and Goldstein, 2004),

iv) metabolic pathways in microbes and eukaryotes (Daniel and Danson, 1995; Hengeveld and Fedonkin, 2004),

v) prebiotic thiol and phosphate chemistry (Heinen and Lauwers, 1996; de Zwart et al., 2004)

### **References**

- Baymann, F., et al., (2003). The redox protein construction kit: pre-last universal common ancestor evolution of energy-conserving enzymes. *Philosophical Transactions of the Royal Society of London* 358B: 267-274.
- Braun, D. and Libchaber, A. (2004). Thermal force approach to molecular evolution: *Physical Biology* 1: 1-8
- Daniel, R.M., Danson, M.J., 1995, Did primitive microorganisms use nonheme iron proteins in place of NAD/P? *Journal of Molecular Evolution*, v. 40, p. 559-563.
- de Zwart, I.I., Meade, S.J., and Pratt, A.J. (2004). Biomimetic phosphoryl transfer catalysed by iron(II)-mineral precipitates. *Geochimica et Cosmochimica Acta* 68: 4093-4098.
- Fontecilla-Camps, J.C. and Ragsdale, S.W. (1999) Nickel-iron-sulfur active sites: Hydrogenase and CO dehydrogenase. *Advances in Inorganic Chemistry* 47: 283-333.
- Heinen, W. and Lauwers, A.M. (1996). Organic sulfur compounds resulting from the interaction of iron sulfide, hydrogen sulfide and carbon dioxide in an anaerobic aqueous environment. *Origins Life Evolution of the Biosphere* 26: 131-150.
- Hengeveld, R. and M.A. Fedonkin (2004). Causes and consequences of eukaryotization through mutualistic endosymbiosis and compartmentalization. *Acta Biotheoretica* 52: 105-154.
- Kelley, D.S., Karson, J.A., Blackman, D.K. et al., (2001). An off-axis hydrothermal vent field near the Mid-Atlantic Ridge at 30° N. *Nature* 412: 145-149.
- Koonin, E.V. and Martin, W. (2005). On the origin of genomes and cells within inorganic compartments. *Trends in Genetics* 21: 647-654.
- Imai, E., (1999) Eolongation of oligopeptides in a simulated submarine hydrothermal system, *Science* **283**, 831-833.
- Rickard, D., Butler, I.B. and Olroyd, A. (2001). A novel iron sulphide switch and its implications for earth and planetary science. *Earth and Planetary Science Letters* 189: 85-91.
- Sauer, K. and Yachandra, V.K. (2002). A possible evolutionary origin for the Mn<sub>4</sub> cluster of the photosynthetic water oxidation complex from natural Mn<sub>2</sub> precipitates in the early ocean. *Proceedings of the National Academy of Sciences, USA* 99: 8631-8636.
- Stone, D.A. and Goldstein, R.E. (2004). Tubular precipitation and redox gradients on a bubbling template. *Proceedings of the National Academy of Science, USA* 101: 11537-11541.

### **Background to my research on the origin of life**

It was the discovery of fossil hydrothermal chimneys that inspired our development of the hydrothermal theory of the origin of life at a submarine spring. Beginning as correspondence to *Nature* (Russell et al. 1988), I, and my collaborators have published over 20 papers on theoretical and experimental aspects of our autotrophic hypothesis. Significant milestones were:

1. The recognition that basic to life's emergence was the formation of mineral compartments across which steep redox, pH and ionic gradients were poised (Russell et al. 1989 et seq.). We demonstrated that the pH gradient acting across the membrane (acid outside, alkaline inside) constituted a natural protonmotive force, and that the redox gradient could augment this force by chemiosmosis (e.g., Russell and Hall, 1997). The energy focussed across the barrier in this way was commensurate with that required by all life, i.e., a volt or less (Russell and Hall, 1997). Also the compartments solved the "concentration problem" (Martin and Russell, 2003).
2. I predicted the discovery of off-ridge alkaline hydrothermal springs of moderate temperature in Russell et al. (1994). The discovery of such an alkaline spring has been reported by Kelley et al. (2001, 2005).
3. As expected, these springs contained significant (i.e., 15 mmol/litre) H<sub>2</sub>, which, we had argued, could have reduced the CO<sub>2</sub> concentrated in the first oceans. This process evolved from a geochemical feedback system to an autogenic metabolism (Russell et al., 1993,1994).
4. Our laboratory experiments have demonstrated the facility with which amines, organic sulfides and polysulfides may be synthesised in an aqueous solution of HCHO, NH<sub>4</sub>CO<sup>-</sup>, MgCl<sub>2</sub>.6H<sub>2</sub>O, H<sub>2</sub>S and NH<sub>3</sub> (Cole et al., 1994). We have also reduced a cyclic ketone with H<sub>2</sub>S to trisulfide (Kaschke et al., 1994). Since then we have successfully repeated the acetate synthesis of Huber and Wäschershäuser (1997; Russell et al., 1998), but have not been able to reduce CO<sub>2</sub> directly. It is for this reason that I am turning away from autoclave synthesis and to the use of open system reactor experiments (Russell et al., 2003).
5. We were the first to demonstrate the structural similarity between greigite (a Ni-Fe-sulfide) and the active centres of various essential proteins that must have existed within the first microbes (e.g., CODH/ACS & ferredoxins) (Russell et al., 1994). Subsequently we showed how moieties of this mineral structure could be sequestered by short achiral peptides and have acted as the first electron transfer agents, hydrogenases and synthases (Russell et al., 2003; Milner-White, Russell, 2005).
6. Deriving from the idea that metals and metal sulfides were first to do the biochemical work of

CO<sub>2</sub> fixation, we have demonstrated how the acetyl-coenzyme-A pathway could have developed in the hydrothermal mound - a mound that acted as a flow reactor and affinity column (Russell and Martin, 2004).

7. A genetic control may also be understood in terms of molecular recognitions at mineral surfaces, specifically because of affinities between arrays of triplets of nucleic acid bases and the side chains of particular abiotic amino acids (Russell, Mellersh and Hall, 2003).

8. The theory has now been developed to include the early differentiation of the archaeal from the bacterial domain. These prokaryotes expanded to comprise the "deep biosphere" (Martin and Russell, 2003; Russell and Arndt, 2005).

9. The continued coupling between life and convection can also explain the onset of oxygenic photosynthesis (Russell and Arndt, 2005). A feature of this latest model is that a Ca-Mn-oxide entity in littoral manganiferous sediments was co-opted as the Oxygen-Evolving Complex by PS2 in the cyanobacterial ancestor (Russell and Hall, 2001). Thus, we argue that both chemosynthesis and oxygenic photosynthesis emerged within the confines of mineral constituents (Ni-Fe sulfides and Ca-Mn oxides respectively) — constituents that were then co-opted as catalytic cubane-bearing catalysts by their prokaryotic hosts.

10. Understanding the general nature of hydrothermal systems has led to research and publication on the likelihood of life on Mars and suggestions as to exploration methods (Russell and Hall, 1999; Russell et al., 1999). While it is common knowledge that methane, and more especially oxygen, are indicative of biotic waste effluent, we point out that acetate in ice or water on another planet is a certain indicator of the presence of life (cf. Russell and Martin, 2004).