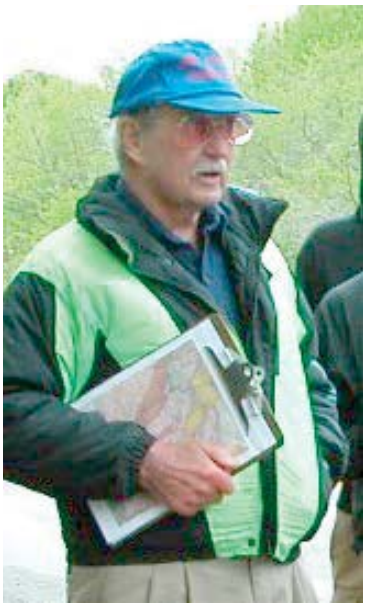
GEOLOGY at SMU

An occasional newsletter from Earth Sciences for alumni and friends: September, 2009

Shuler Foscue Chair Eugene Herrin

Explosions Drive New Infrasound Studies



Professor Gene Herrin leading an undergraduate field trip into the Arbuckle Mountains, Oklahoma.

The April 2008 issue of *Acoustics Today* featured a cover story on high altitude rocket explosions recorded with infrasound arrays. SMU geophysicist Eugene Herrin and the late Henry Bass were the lead authors. Infrasound waves have frequencies below the limit of human hearing (20 cycles per second).

Infrasound waves can be observed by barometers. According to Herrin, the 1883 eruption of Krakatoa was one of the first instances of a major volcanic eruption being remotely sensed by infrasound. Atmospheric nuclear testing provided an impetus for understanding infrasound that declined after the Nuclear Test Ban Treaty of 1963 banned nuclear tests under water, in the air or in outer space. With the new Comprehensive Test Ban Treaty (CTBT), Gene Herrin and his SMU colleagues are leading a resurgence in the geophysical applications of infrasound. This is nothing new for Gene, whose career has taken several turns.

When Gene Herrin completed his Master's Degree at SMU, he walked into the late Claude Albritton's office to report on the wonderful job offer he had received from an oil company with a car and a signing bonus. According to Gene, Claude Albritton asked why Gene was entertaining job offers from oil companies when he was going on to another graduate school for a PhD. Gene was surprised by Albrition's response as he had not applied to any graduate schools. Claude told him to come back to his office after the weekend. When Herrin returned, he was congratulated on being appointed as the famous Harvard geologist Marland Billing's new teaching assistant in structural geology. Billings' book *Introduction to Structural Geology* was the commonly used textbook at the time.

Geophysics is the better for Claude's efforts. Gene did some early work on heat flow with geophysicist Francis Birch before concentrating his efforts in seismology. He published a seminal paper on travel time curves for the mantle which formed the basis of methods to precisely locate earthquakes on an upgraded worldwide network. Earthquake locations and focal mechanisms (type of fault movement) were critical for the subsequent plate tectonic revolution. Gene was one of the first to use P-waves in the upper mantle to show that there were variations in the physical properties of the uppermost mantle immediately beneath the continental crust of the United States, critical for the precision location of earthquakes at regional distances.

Eugene Thornton Herrin

- SMU B.S., Physics; M.S., Geology
- Harvard Ph.D. Geophysics
- Interests **seismology, infrasound, heat flow, structural geology**
- Fellow of the Geological Society of America and the American Geophysical Union

A seismological "arms" race paralleled the nuclear arms race underground because seismology became a major part of the intelligence community's efforts to monitor the development and proliferation of nuclear weapons (page 6). Gene was a leader in developing geophysical processing tools necessary to discriminate between shallow manmade explosions and natural earthquakes. His interest in improving the quality of seismic data was not limited to data processing; Gene had a long term relationship with Geotech initially run by William Heroy Sr., and Jack Hamilton, the CEO when it became Teledyne-Geotech. This association

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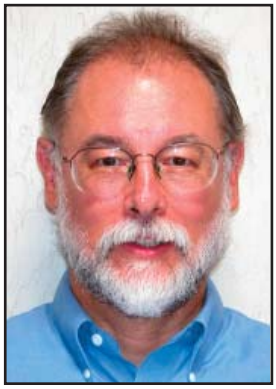
Chairman's Report

Meteorites: Links between planets and stars, clues to the formation of the elements



Robert T. Gregory

The Hamilton Visiting Scholar in Geophysics lecture series has had a nuclear theme as of late. Robert N. Clayton, a stable isotope geo- and cosmochemist from the University of Chicago presented a public lecture entitled "*Stardust in the Laboratory.*" Clayton's visit was followed by Professor Rodney Ewing of the University of Michigan who talked about the nuclear fuel cycle and the applications of mineralogy to the safe disposal and storage of nuclear waste. Dr. Richard Carlson, Department of Terrestrial Magnetism of the Carnegie Institute, kicked off SMU's *Year of Darwin* early and continued with the nuclear theme in a lecture entitled,"*A History of Earth Formation.*"

With the exception of hydrogen, lithium, beryllium, boron and most of the helium, the remaining long-lived abundant elements and isotopes are made through nuclear interactions in stars. Isotopes are elements that differ from each other only in the number of neutrons contained by their nucleii. The light elements are leftover from the first hour or so after the "Big Bang," the current inferred beginning of our universe. At Earth surface conditions, most reactions involving matter occur between atoms and molecules whose interactions are through the familiar electromagnetic force. This type of chemistry dates from about a half million years after the Big Bang; it would have been pretty simple (e.g. H_2 or HD or a few alkali hydrides). As the expanding universe cooled, slight concentrations of matter allowed the first stars to form through gravitational contraction.

Our Sun is an average star, some 300 hundred thousand times more massive than the Earth, and as such, the interior of the Sun is extremely hot (some 10 million degrees). It is so hot in the core of the Sun that hydrogen nucleii can collide and stick together to make helium. Stars spend most of their lifetimes fusing hydrogen to make helium. This special time of helium production is called the main sequence. Indeed, the oldest stars in the Milky Way are almost entirely hydrogen and helium and they have been on the main sequence for most (~95%) of the history of the cosmos. Astronomers can still observe examples of the first stars that were smaller than our Sun. The early massive stars are long gone because they progress through the evolutionary cycle quite rapidly, millions of year timescales instead of billions of years for stars more like our Sun.

As stars age, they use up the hydrogen in their cores and once the rate of fusion slows down, gravity once again takes over so that the core of the star becomes even hotter and more dense. At the same time, the outer envelope of the star is expanding outward and the star is said to be a "red giant." For our solar system, this might mark the end of the Earth (death by vaporization!). When the core of the star gets hot enough for helium nucleii to collide and fuse, the star can now produce the carbon that is essential for life. The helium fusion flash now causes the star to burn extremely bright. Our Sun will spend less than 5% of its lifetime during this later phase and will die as a white dwarf, a ball of carbon about the size of the Moon.

Depending on the size of the star, a series of successive fusion intervals involving He, or the fusion products of He, punctuated by core collapse allows the star to make the most important planet-building elements, oxygen, magnesium, silicon and iron, in that order. It is no accident that nature favors nucleii whose atomic mass numbers represent multiplication by 4, the mass number of helium, starting with ^{12}C. Nucleii of iron whose masses have atomic mass number (the number of neutrons plus the number of protons) of 56 (4 X 14) are the most stable form of nuclear matter. Above mass 56, nuclear fusion reactions are endothermic and thus allow the core of the star to cool so that gravity takes over. The final gravitational collapse leads to a white dwarf (a ball of carbon for a small star), a neutron star or a black hole (for a star that makes iron). The implosion of the large star's forming neutron core is so violent, the rebound from the shock blows most of the mass of the star away to form a planetary nebula, ready for the next star forming event. The star has gone "supernova."

The flood of neutrons produced during the end stages of stellar evolution showers the nucleii of elements previously produced during fusion reactions in the star. The nucleii swell in size and develop an excess of neutrons that makes them unstable or radioactive. These elements spontaneously decay into other elements, the alchemists' dreams of prior centuries.The bloated nucleii can lower their energy and their mass (recall $E=mc^2$) by a variety of mechanisms not limited to shedding

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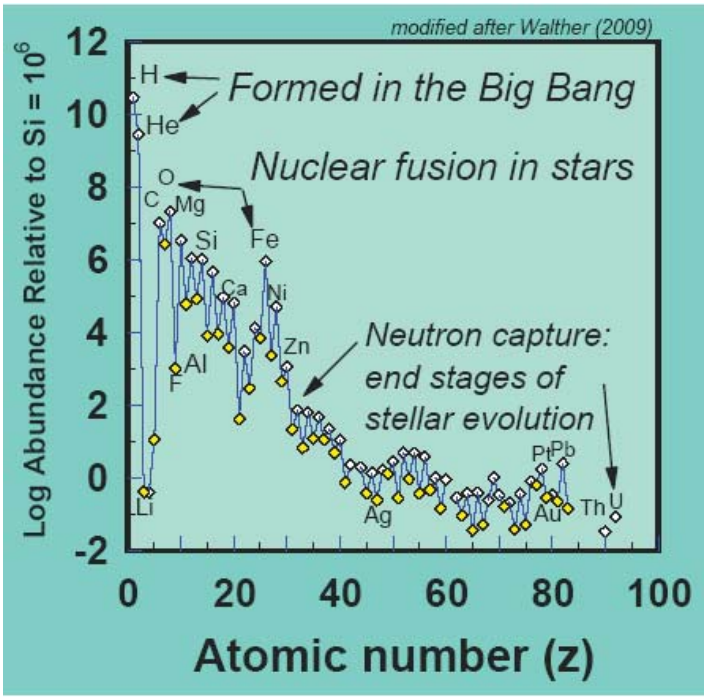


The natural abundances of the elements normalized to Si =10^6 atoms are plotted against the number of protons in the nucleus (atomic number, Z). Hydrogen, helium, lithium, beryllium and boron were created in the Big Bang. A 12:1 H/He ratio on the graph leads to a 3:1 weight ratio for the cosmos. On the scale of the graph, H is more than 10^4 times more abundant than Si. The planet building elements (e.g. Fe, Mg, Si and O) are formed by fusion reactions in the cores of stars. Elements of whose mass numbers (A=Z+N, where N is the neutron number) are multiples of 4 are most abundant. Above mass 56, iron, fusion is no longer energetically favorable, so elements grow by neutron capture and radioactive transformations that occur as stars implode while ejecting most of their mass now seeded with new heavy elements back into the cosmos ready to combine back into new stars.

electrons as β particles, transforming a neutron into a lower mass proton, or by spitting out α particles (helium nucleii) to move towards more stable nuclear configurations.

Most of the isotopes produced in a supernova event are gone in an instant. Supernovas ignite and dim along intensity *versus* time curves that follow decay laws for abundant short-lived radioactive elements. Many decay away to stable isotopes which we can use as tracers and geothermometers (the work described by Clayton). Nuclear fuels provide heat to drive steam turbines that make electricity and make the short-lived nuclides that have to be sequestered for at least 100,000 years and possibly a million years, the topic of Ewing. Others are metastable on the timescale of a solar system or the universe so that they become the absolute chronometers for geochronology, Carlson's topic.

Recent advances in isotope geochemistry have changed our understanding of the origin of the Solar System and the Earth. Meteorites, and in particular, chondritic meteorites, are presumed to be the starting composition of the Earth. Chondritic meteorites are named for the their spherical inclusions called chondrules (page 4). Chrondrules are predominantly composed of high temperature condensates, minerals that form at high temperature.

Carbonaceous chondrites are mechanical aggregates composed of high and low temperature condensates from the solar nebula that produced our Sun. They also contain organic compounds and what appear to be pre-solar dust and grains. Refractory inclusions containing minerals rich in Ca and Al (page 4) are now known to carry isotope anomalies resulting from stellar processes or from the *in-situ* decay products of radionuclides that are now extinct, i.e. the decay products of radioisotopes injected into the nebula by a nearby supernova some 4.6 billion years ago. These meteorites bear witness to the formation of the Solar System and the Sun. However, geochemists now can step back farther and ask questions about the origin of the elements themselves. The origin and formation of the elements that make up ordinary matter is now part of our cosmological heritage.

Continued from Page 1

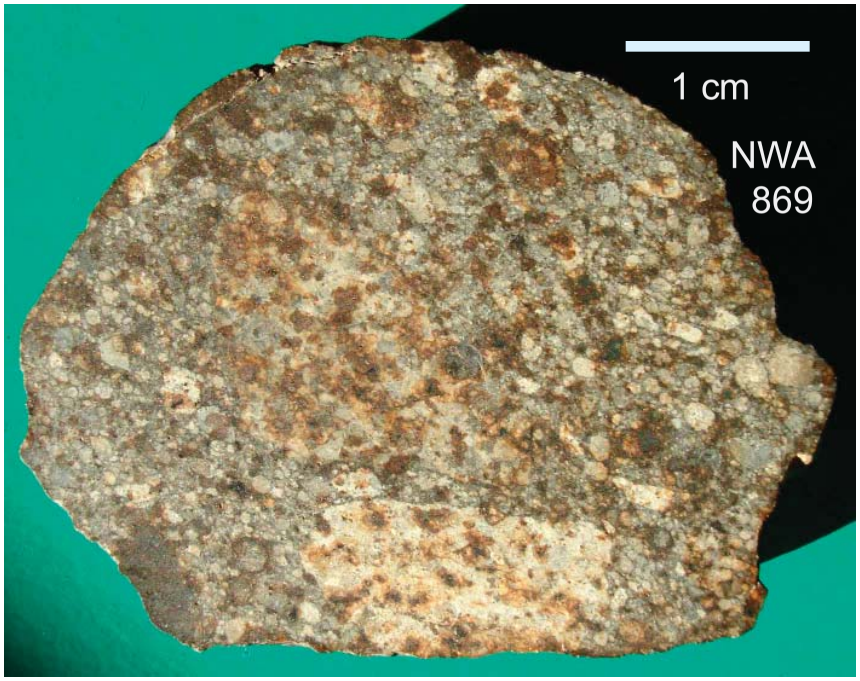
between Herrin, his students, and Geotech was important for the company's success, establishing the excellent relationship with Jack Hamilton that continues to this day through the Hamilton Visiting Scholar in Geophysics program.

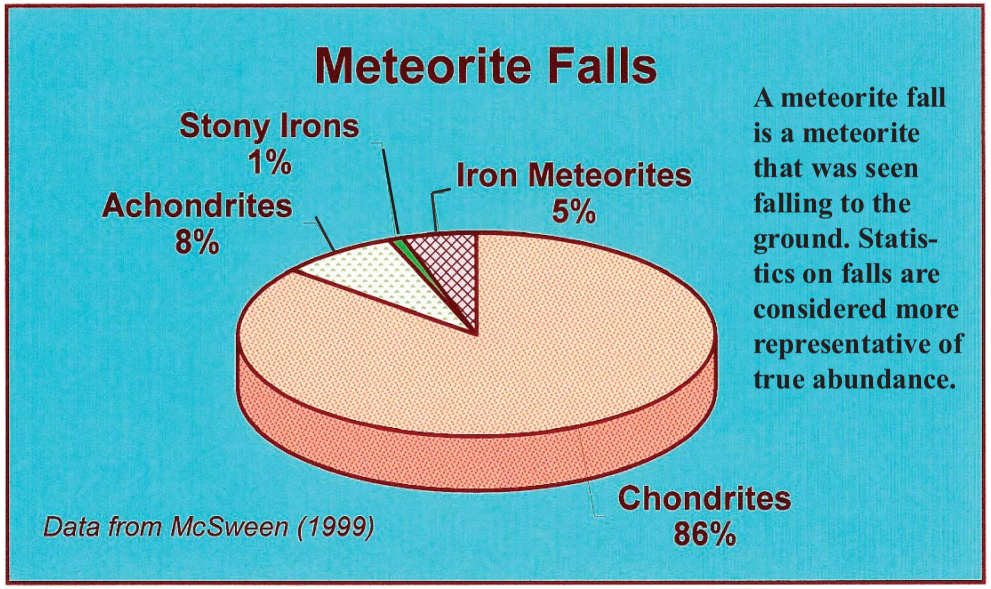
With nuclear arms test yield reductions, Gene became a leader in the development of array seismology that makes use of multiple seismometers located over 10's of square kilometers working in concert to detect small earthquakes at great distances. With protocols developed for the Comprehensive Test Ban Treaty, these same arrays are being retrofitted with barometers to detect infrasound in seismo-acoustic arrays as part of a more comprehensive program to monitor both the subsurface and the atmosphere.

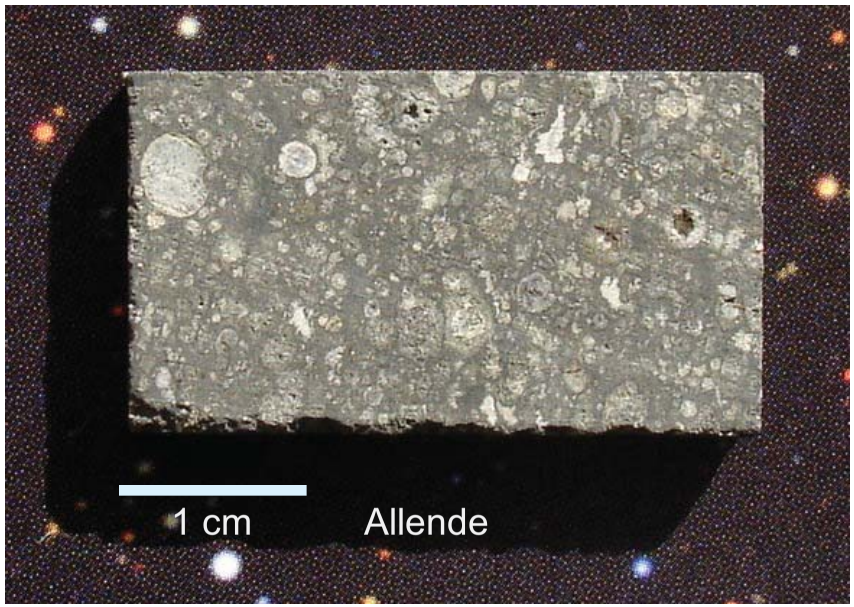
The high altitude rocket detonations featured in *Acoustics Today* provide an opportunity to examine infrasound propagation from sources that are well characterized in terms of location, time, and energy. The experiments were partially motivated by the infrasound signals recorded when the Space Shuttle broke up over Texas in 2003. Unlike the solid Earth which has a large scale stable structure, the atmosphere changes rapidly affecting the propagation of infrasound waves. Modelling efforts have been compromised by the lack of well calibrated events, a need being satisfied through these experiments and those that continued with surface explosions in Utah this summer. The recent experiments had lines of receivers radiating away from the source, not unlike what is done in seismic refraction.This series of experiments is helping fuel the renaissance in infrasound studies.

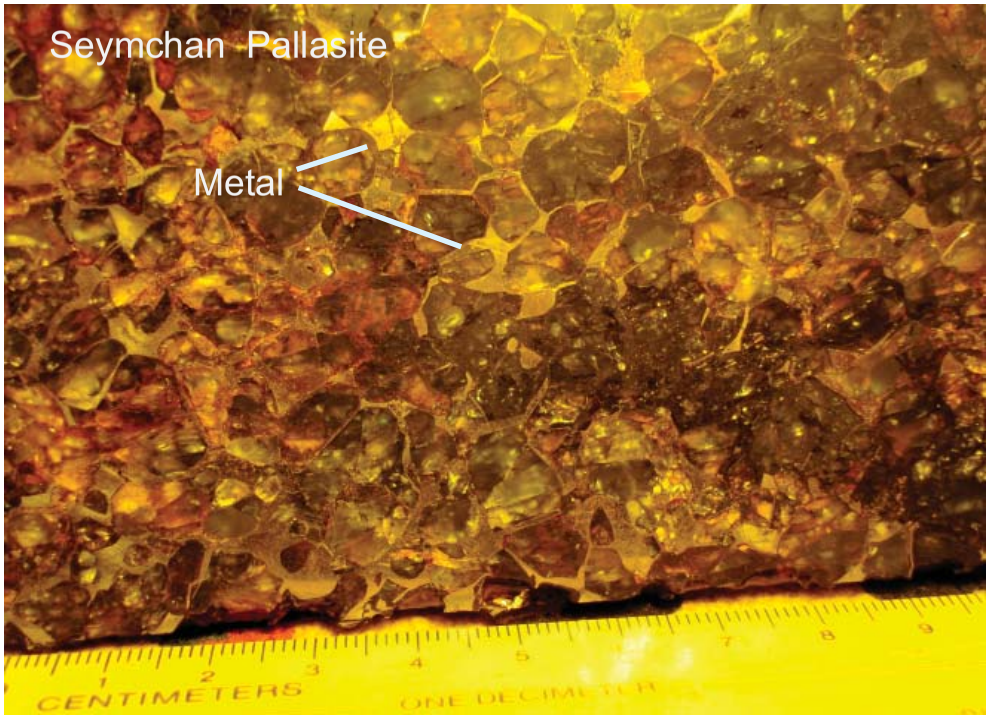
The Hamilton Visiting Scholar in Geophysics Series, now in its second decade, celebrates the collaboration between Geotech and SMU.

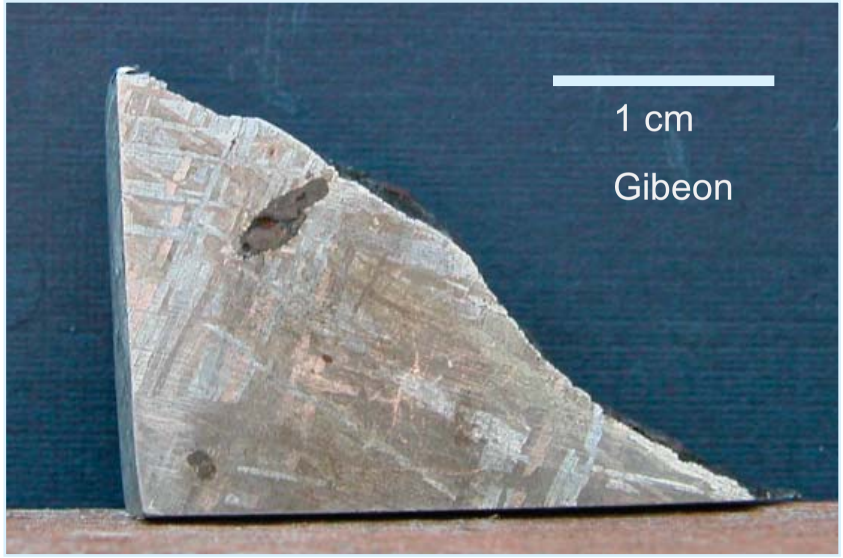
Meteorites as Extraterrestrial Visitors From Space: Leftovers from the Formation of the Solar System



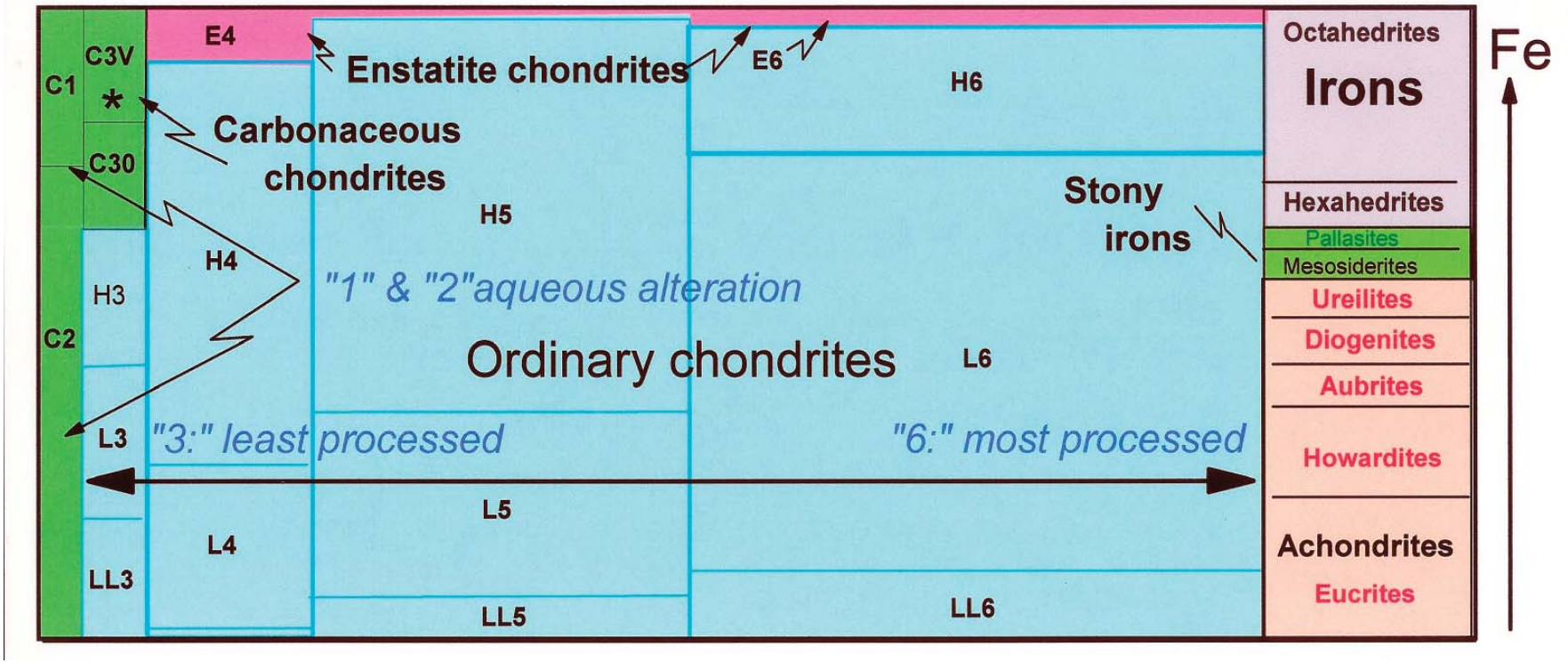








Chondrites are composed of chrondrules condensed at high temperatures, clasts, grains of metal, and matrix which may or may not be carbonaceous (condensed at low temperature) depending upon the thermal history. NWA 869, a brecciated **L5 chondrite** with carbonaceous inclusions found in 1999 in Algeria. **Allende** is most famous for its isotope anomalies found in its refractory inclusions (white clots). Allende contains excess ^{26}Mg that correlates with Al content indicative of the presence at the time of formation of the short-lived nuclide ^{26}Al with a half-life of approximately 730,000 years. The chondritic meteorites cluster at 4.56 billion years old and are considered to be a good average of the nebula, i.e. they have solar abundances minus hydrogen, helium, and other volatile elements. The Gibeon **Fe-Ni meteorite** (left) is famous for its silver isotope anomalies consistent with now extinct palladium, the chronometer that chronicles the speed of core formation in protoplanets on timescales of 10 million years. The **pallasite** (above) is from Russia and consists of cm scale olivine crystals in a matrix of metal.



The predominance of chondrites suggests that the planets accreted by collisions of mechanical mixtures of high & low temperature materials and not by pure chemical condensation from the nebula. C stands for carbonaceous chondrite (the "O" and "V" stand for a type locality; the * stands for Allende). LL stands for very low iron; L, low iron; and H, high iron. Types 1 and 2 exhibit aqueous alteration whereas Types 3 through 6 indicate increasing degrees of metamorphism (modified from Wood, 1990, *the New Solar System 3rd Ed)*. The meteorites on Earth today mainly originated from the asteroid belt; a few types are now thought to be from Mars and the Moon; the latter are all members of the achondritic group (right column). The Martian achondrites are identified on the basis of their noble gas ratios which are similar to those measured by NASA's Viking Mission and ^{18}O:^{17}O:^{16}O ratios. The Howardites, Eucrites, and Diogenites (HED meteorites) are thought to be fragments of the asteroid Vesta.

Leighton Steward publishes book on, "Fire, Ice and Paradise:" A primer on climate change

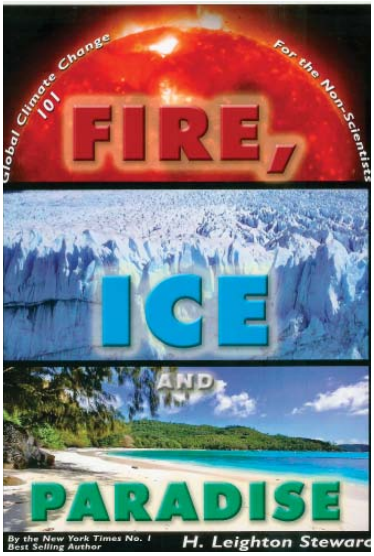
Leighton Steward, B.S. (1957) and M.S. (1959), has now published his third book. The previous two best-selling books championed the benefits of low sugar diets for adults and children and aptly carried "Sugarbusters" in the title. The books were appreciated for their clear exposition on medical matters in a language suited to the "man in the street." For his latest effort, Leighton uses his geologic background to apply the same approach to the problem of climate.

Whereas in the first books, the rationing of dietary sugar is seen as beneficial for preventing obesity, he does not see the need to ration carbon dioxide to prevent some envisioned future climate catastrophe. Leighton catalogs the drivers of climate change from a geologic perspective, examining the timescales and magnitudes of the effects in a qualitative way.

Unlike the case of sugar, for carbon dioxide, he is not willing to make the connection between man-made carbon dioxide production due to consumption of fossil fuels and climate change. The climate system, in his view, is too complicated to remove the uncertainty for him involving the impact of anthropogenic CO_2 on past or future temperature change.

Instead Leighton proposes that we study the climate system in much more detail with the tools that only have become available to us within the last 50 years. As Leighton says, "the library is now open," while exhibiting his discomfort with popular oversimplifications on what drives climate change. He equates ameliorating atmospheric CO_2 by government regulation with the statement that CO_2 is the primary driver of climate. If the latter is not true, in his view, there is no pressing need for action with respect to the former.

The book, *Fire, Ice and Paradise*, joins a crowded marketplace with a number of other books advocating for action in preparation for the upcoming climate talks in Copenhagen. Some of this is being driven by new data that indicate that the climate system can flip modes from cool to warm on rapid timescales. The problem as always is the translation of scientific knowledge with its inherit levels of uncertainty into policies driven by some political consensus or, at best, from a slim majority.

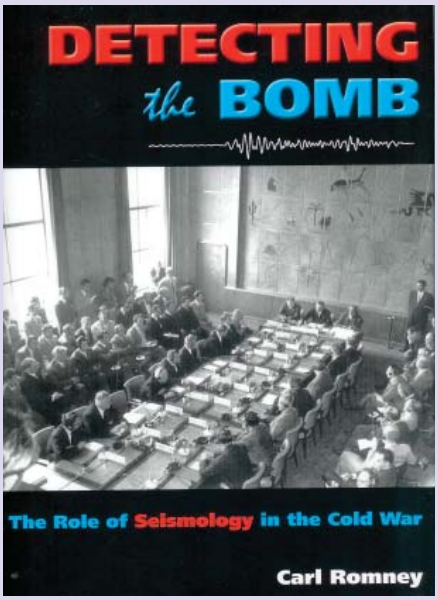


Leighton Steward has been recognized for his environmental advocacy for the wetlands of Lousiana. The book is available from online booksellers or directly from the publisher by calling 1-888-280-7715.

Carl Romney was the first Hamilton Visiting Scholar in Geophysics. Now he has published the first book resulting from the lecture series. *Detecting the Bomb* documents how seismology was crucial for monitoring nuclear detonations in the cold war. Seismometers and seismologists were present from the first Trinity Test at Alamagordo, New Mexico. The importance of seismology to the nuclear age continues to this day with the monitoring of the current Comprehensive Test Ban Treaty.

The race to be able to adequately detect and discriminate nuclear tests from natural earthquakes by scientific methods was a parallel "arms" race in the movement to control the spread of nuclear weapons. The stark realization of the terrible nature of these weapons resulted in a desire to control their spread within a year of the Hiroshima and Nagasaki blasts. Richard Feynman, a member of the Manhatten Project, once remarked quoting an eastern proverb, "technology is like a key, it equally opens the gates of heaven or the gates of hell."

As Carl Romney notes, the impact of the nuclear age on the science of seismology would have been unimaginable to a student of geophysics before the Cold War. The application of earth science in the national interest contributed much to improve the science with benefits towards the understanding of the structure of the Earth and how it operates on a global, plate tectonic scale.



News of alumni, faculty, & friends

Dr. David DesMarais, NASA Ames, will be the Fall 2009 Hamilton Visiting Scholar in Geophysics. Currently, DeMarais is a member of NASA's Astrobiology Institute, a consortium of workers from laboratories and universities interested in issues related to the possibility of life elsewhere in the universe. He is a participant in ongong missions to Mars that are operating on the surface as well as from orbit. The public lecture, to be held at the Frontiers of Flight Museum on November 17th at Love Field, will examine the results of the robotic missions to Mars and the implications of the search for life there.

Don L Anderson, Caltech, was the Hamilton Visiting Scholar for Spring 2009. Don lectured on his *New Theory of the Earth* which attempts to fully integrate the results of solid earth geophysics with geochemistry in order to gain a better understanding of how the mantle and crust evolve through time. His public lecture was entitled, *The Continental Drip Hypothesis,* which describes how the cold mafic roots of continents can induce secondary mantle convection which in Anderson's view can account for much intraplate volcanism. Anderson is a holder of the Crafoord Prize given out by the same group that awards Nobel Prizes.

Marie Arrowsmith (Ph.D., 2009) defended her thesis entitled *Mining Explosion Identification as an a Application of Treaty Verification.* She is now working at Los Alamos National Laboratory.

Weimin Feng (Ph.D., 2009) defended his dissertation on *Stable Isotope Studies of Selected Synthetic and Pedogenic Hydroxyl-bearing Minerals and Some Implications for the Environment of the Mid-Cretaceous.* He is a post-doctoral fellow at UT Austin.

Sougata Halder (Ph.D., 2009) completed her dissertation: *Experimental Determination of the Dissolution Mechanism of Ca and Mg Pyroxenes /Pyroxenoids in Alkaline Solutions* while caring for her new son, Sreejit.

Juan Garcia Massini (Ph.D., 2009) defended his dissertation entitled, *Paleoenvironment Reconstruction of Late Oligocene Deposits from the Northwestern Ethiopian Plateau*. Juan is a postdoctoral fellow in his native Argentina funded by its equivalent of NSF: CONICET.

Professor David Blackwell and **Maria Richards** will host the fourth two day conference on *Geothermal Energy Utilization Associated with Oil & Gas Development.* The conference will be held in SMU's Collins Executive Center where the 2008 conference attracted >200 interested parties from science, engineering, and business. The dates are November 3rd-4th; see *www. smu. edu/geothermal* for the details.

Wallace Broecker (D.S., 2008) has published a book entitled *Fixing Climate: What Past Climate Changes Reveal about the Current Threat--and How to Counter It* with co-author Robert Kunzig, ISBN -13:978-0-8090-4501-3. Global action, in their view, should be tied to direct threats from warming, economically important, tied to threats not preventable by some other means, and tied to effects that are coming on fast.

Evan Dedo (B.S.; B.B.A, 2009) has relocated to Alaska where he will be working for an oil field services company involved in platform construction on the North Slope.

Andres Ruzo (B.S.; B.B.A., 2009), has joined the PhD program in geothermal energy. As an undergraduate his "Big iDeas" entry with Elizabeth Corey on producing geothermal energy from wells on the SMU campus was one of the winning projects in a competition sponsored by the Provost's Office.

Nicholas Rosenau, a second year graduate student, received a prestigious NSF Graduate Fellowship to continue his paleoclimate studies with Dr. Neil Tabor. NSF Postdoctoral Fellow, **Dr. Ellen Curano** departed this summer to take a job as an Assistant Professor at University of Miami, Ohio. Ellen was collaborating on **Dr. Bonnie Jacobs'** Ethiopian project.

Professor Brian Stump, Chris Hayward (Ph.D., 1999), and undergraduate **Ashley Howe (B.S., 2010)** deployed seismometers in north Texas to investigate the swarms of earthquakes around Clebourne and DFW Airport. This work has attracted lots of media attention including national outlets such as *Bloomberg News* and the *New York Times.*

Professor Louis Jacobs participated in the faculty Darwin Symposium highlighting the global effort of his work and the importance of the theory of evolution to the general discipline of geology.

Dr. YurenaYanes-Lopez is visiting the department for eight months funded on a post-doctoral fellowship by the government of Spain. She is working in the Stable Isotope Laboratory with **Professor Crayton Yapp**. She has been a frequent visitor to many classrooms during the fall term measuring the concentration and isotope ratio of carbon dioxide in the classrooms.

Robert Rogers (B.S. Geology, 2008) has joined a master's program in hazards geophysics at University College London.

Dedman College Dean **Cordelia Candelaria** resigned at the end of spring semester, 2009, for personal reasons, after one year of service. In her first year, she adjudicated the successful tenure and promotion case for **Dr. Neil Tabor** who is now an associate professor with tenure. The Department expresses its gratitude to Dean Candelaria.

Please share any career news and interesting photos with us for use in our newsletter. Contact Stephanie Schwob or Sandi Herrera at 214-768-2750.

****All prior issues of* Geology at SMU *can be found online.***

http://www.smu.edu/earthsciences

Roy M. Huffington Department of Earth Sciences

David D. Blackwell, Hamilton Professor, Ph.D., Harvard. Geothermal studies and their application to plate tectonics, energy resource estimates and geothermal exploration.

James E. Brooks, Professor *Emeritus,* Ph.D., University of Washington. Stratigraphy and Sedimentology

Robert T. Gregory, Professor, Chair, Ph.D., California Institute of Technology. Stable isotope geology and geochemistry, evolution of earth's fluid envelope and lithosphere.

Eugene T. Herrin, Shuler-Foscue Professor, Ph.D., Harvard. Theoretical and applied seismology, solid earth properties, computer analysis of geophysical data.

Louis L. Jacobs, Professor, Ph.D., University of Arizona. President of the Institute for the Study of Earth and Man. Vertebrate paleontology, evolution.

Bonnie F. Jacobs, Associate Professor and Chair of the Environmental Science Program, Ph.D., University of Arizona. Paleobotany & palynology of the Cenozoic.

A. Lee McAlester, Professor, Ph.D.,Yale University. Paleoecology, evolutionary theory, petroleum geology.

James E. Quick, Professor, Ph.D., California Institute of Technology. Igneous and metamorphic petrology, tectonics, volcanology.

Brian W. Stump, Albritton Professor, Ph.D., University of California, Berkeley. Seismology, seismic source theory, regional waves, seismic and infrasonic instrumentation.

Neil J. Tabor, Associate Professor, Ph.D., University of California, Davis. Sedimentology, paleosols, stable isotopes and paleoclimate.

John V. Walther, Matthews Professor, Ph.D., University of California, Berkeley. Experimental and theoretical aqueous geochemistry, fluid-mineral interactions in the crust.

Crayton J. Yapp, Professor, Ph.D., California Institute of Technology. Stable isotope geochemistry applied to the study of paleoclimates, paleoatmospheres, and the hydrologic cycle.

Adjunct Faculty

Steve Bergman, Research Professor, Ph.D., Princeton University. Tectonics, petrology & geochronology.

Anthony Fiorillo, Research Professor, Ph.D., Pennsylvania. Museum of Nature & Science. Vertebrate paleontology.

Jason R. McKenna, Research Assistant Professor, Ph.D., Southern Methodist University. Applied Geophysics.

Mihan H. McKenna, Research Assistant Professor, Ph.D., Southern Methodist University. Seismology and Infrasound.

L. L. "Roy" Mink, Research Professor, Ph.D., University of Idaho. Geothermal energy and hydrology.

Troy Stuckey, Adjunct Associate Professor, Ph.D., University of North Texas. EPA. Environmental Science and Policy.

John Wagner, Research Professor, Ph.D., University of Texas, Dallas. Chief Geologist, Nexen Petroleum, USA.

Alisa J. Winkler, Research Professor, Ph.D., Southern Methodist University, Mammalian paleontology, anatomy.

Dale A.Winkler, Director, Shuler Museum of Paleontology, Ph.D., UT Austin. Paleontology, paleoecology, stratigraphy.

Pierre A. Zippi, Research Professor, Ph.D., University of Toronto. Biostratigraphy, palynology, and oil exploration.

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