International Big History Association

Layers within layers, complexity built upon complexity

Dances with the Earth

Call for Papers

Antonio Vélez Montoya

Members' Newsletter
Volume IV Number 2

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Layers within layers, complexity built upon complexity

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I am currently working on my Big History of Grass book which will be completed in 2014. I have been investigating the history of grass from its first divergence from other angiosperms, through to the present and even future. I've also been working on the animals that evolved to utilize grass resources, and ultimately the way in which humanity harnessed those plants and animals to create the modern era. I have tried and failed to imagine a path to the current level of human complexity without grasses such as wheat, barley, corn, rice, millet, sugar cane, and associated animals like sheep, cows, or horses. This project has consumed years of my life and forced me to go far beyond my comfort zone in such fields as genetics, biology, chemistry and evolution. During the course of this project I have repeatedly challenged myself to look at things from the plant or animal's point of view, as Jared Diamond first invited me to consider the point of view of a virus in his chapter "The Lethal Gift of Livestock" in Guns, Germs and Steel. Doing this has forced me to rethink many of my assumptions about the history of domestication and the role of humanity in the modern era. Rather than go into more detail about the history of grass, I wanted to take this opportunity of writing for the IBHA newsletter to explore some of the notions that have come to me during this project that go well beyond the topic of the book itself.

Working on the grass book I have come to appreciate, as never before, how fast our knowledge is evolving. The cost of genetic studies has plunged even faster than the speed that computing power has improved, and we are being flooded with new information. It will be years before the implications of the latest studies are understood, and conclusions that were widely accepted just three or four years ago are being overturned. My rule of thumb has been to regard anything written on genetics prior to 2010 as useful only for historical perspective. This has been a paradigm shift for someone trained as an ancient historian and my assumption that anything written in the last two decades is "recent" and even work written decades earlier may still be valid. It is also terrifying to know that many things going into my grass book will be overturned before the book has time to appear on the shelves.

The explosion of knowledge is occurring in almost all fields. The Kepler space telescope was launched in 2009 and suffered fatal malfunctions four years and two months later. (Kepler may soon return to service, in a mission dubbed K2.) Despite the fact that no new data has been collected in over six months, NASA says that more than a year's worth of the gathered information "remains to be fully reviewed and analyzed." Other space telescope missions will gather data at an even faster rate. Gaia, launched in December 2013, aims to create an unprecedented 3D survey of the Milky Way Galaxy. TESS, to be launched in 2017, will closely examine half a million stars and soon after the James Webb Space Telescope (a super-Hubble) will follow. Our human inability to analyze the data as fast as it is gathered is already operating as a breaking mechanism. If this continues, profoundly important new discoveries will be made by our machines months or even years before humanity itself becomes aware of them.

Humanity has overcome this same challenge a number of times before. The invention of writing profoundly changed our ability to disseminate knowledge, and allowed others to build upon pre-


Jonathan Markley

existing knowledge. More recently, the internet has rescued us from another stalling point, allowing us to share and access knowledge with astounding ease. I don't consider myself as particularly old, but in my first years at university research began with card catalogs, books and journal articles physically available in local libraries, and very occasionally an inter-library loan. Without something like the internet, human progress would already have slowed. Without new and equally transformative advances in the future to complement the flood of raw data, the acceleration will slow, and ultimately resolve itself into linear instead of exponential progress.

The existing trend towards crowdsourcing will overcome many of the problems. An example of this is http://www.planethunters.org/ which already recruits interested parties from around the world to help with the search for exoplanets within the sea of existing data. The "Mark One Eyeball" is still superior to any computer in this task. Until we can program computers to analyze in ways similar to the human brain, increased networking of existing human brains provides a way forward. It is ultimately such a useful tool that I believe the day is rapidly approaching where incentives and actual payments will become common in order to lure ever more people into this type of effort.

There is a tendency to dismiss internet social networking and search engines as mechanisms that have contributed to the dumbing down of the next generation, and for their elders to complain about teenagers with their heads in their smartphones, but these are facets of a move towards something every Big Historian should recognize as incredibly important: exponentially better networks of exchange. Google and Facebook are leading the charge to find solutions to the problem of analyzing increased data flows, and they are on the cusp of major breakthroughs. Late in 2013, Facebook announced the establishment of labs around the world to work on the problem of machine learning and artificial intelligence. A little earlier in March 2013, Google acquired DNNResearch, a company working on deep learning and convolutional neural networks. Prior to this, Google image searches tended to rely on identifying key words, but this would often produce

poor results for photos, since image file names usually do not contain relevant words. The new search tools can identify images within photos, such as “sunsets”, “cars”, or “dogs” and as a result Google’s image search results are stunningly improved. The opportunities created by new technologies combined with better networking of human minds fills me with optimism that we will see the exponential growth in knowledge continue.

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I have two small children (now 3 and 5), and I still recall my amazement at their rapid cognitive development in the first year of life. It felt like I was witnessing a computer system that was constantly adding new links and capabilities, progressively “turning on”. In short, it was the reverse of a process I had watched many times in the 1968 classic movie 2001 A Space Odyssey when astronaut David Bowman shut down the artificial intelligence HAL 9000. As Bowman removes components from HAL, the computer tries to persuade him to stop, telling him “my mind is going. I can feel it.” HAL’s voice gets slower and less clear as he reverts to the earliest stages of his existence and eventually shuts down. I am increasingly coming to believe that the human species may be on a similar track. Each step towards increased networking is akin to better connections between synapses in the brain. We already view the collective whole of a beehive or ant hill (known as eusocial structures) as a kind of super-organism working in concert towards a common goal. A Complex organism is similarly a super organism of millions of united single cell creatures working together for the benefit of the whole. This kind of structure took billions of years of development, in which cells began to communicate and cooperate in ever more complex networks, until the partnerships became permanent. Prior to this, the same process can be seen with the emergence of the eukaryotic cells through symbiosis between much simpler prokaryotic cells.

Even much later stages of evolution involved incredibly complex relationships between huge numbers of different species, such as the evolution of the ruminants to take advantage of the difficult to obtain calories contained in grass species. This is the story of a sophisticated alliance between a complex organism and literally countless numbers of bacteria and fungi. For linguistic purists, my use of the word “literally” in this context is indeed literally true since the number of species involved is so great that no complete census has yet been assembled: the number of bacteria in a just one part of the bovine gut needs to be measured in the billions, divided into thousands of species, in addition to huge numbers of fungi, and as yet there is no complete census. Our understanding of the microbial world has advanced to the point where even the human body is now described in terms of the “human biome”. Human cells are outnumbered ten to one by non-human cells within our own bodies, living in (mostly) stable symbiosis. It’s even recently been suggested that the health of the gut bacterial biome has an impact on human mental health just as great as a distressed mind can upset our digestion.

The appearance of complex organisms now appears to be a natural culmination of billions of years of bacterial cross-species cooperation, and in much the same way, I’m coming to see the dramatic changes in the last ten thousand years as less of an anthropecene, and more as the rise of a new cross-species super alliance in the same model as the Cambrian explosion. Humanity did not arise alone, but as part of an alliance of plants and animals in a complex and inseparable web. Grasses, the focus of my own research, always seem to be intimately involved in this story as the prime representative of the plant kingdom, just as homo sapiens are the apex mammal, but without sheep, and legumes, and citrus, and canines, and nuts, and poultry, etc. etc., the story of the modern era would be very different. There are now seven billion human beings, but in this world dominating alliance there are also 20 billion chickens; 1.3 billion cows; 1.1 billion sheep; 225 million hectares of wheat; 160 million hectares each of corn and rice, to name just a few. The total number of organisms in this grand symbiotic bargain becomes many trillions when all the microbes involved are added to the total. When viewed this way, the rise of humanity actually is part of a much broader pattern of Big History involving progressively more complex structures and mutual cooperation between species. If this is indeed the case, it also suggests that the path of the future will continue in this direction towards the creation of a new level of super organism involving complex creatures bound together in the same way bacteria were bound together to form ourselves. Some might suggest that we are almost there already. Modern human society and our plant and animal allies would all suffer devastating losses if the partnership broke.

The super alliance is now entering a new phase that further deepens the mutual dependence between species. The domestication of plants and animals at first was largely accidental, with little understanding of the processes involved, or indeed that there were processes at all. The Columbian Exchange added many new layers to the global partnership, as plants, animals, and micro-organisms were shared between continental zones. Since the age of Gregor Mendel, Charles Darwin and others in the 19th Century, humanity's ability to manipulate plants and animals to our own ends changed from a haphazard process to the widespread and deliberate creation of desirable traits.

In the 21st Century that we are coming to appreciate that there was an equally important microscopic layer in this grand alliance. In the same way we started to deliberately breed plants and animals, the next step involves the deliberate creation of useful traits within microbial life. Biotechnology is developing at a breathtaking speed, and we will soon see custom-made microbes designed to eliminate disease, pollution, cholesterol, and a myriad of other modern maladies. For example, a team in Singapore has successfully engineered E-Coli to find and kill another species of bacteria Pseudomonas aeruginosa involved in causing pneumonia. Human intervention included giving the E-Coli the biological weapon to kill it, a tool to cut through its protective film, and targeting instructions to find and attack that species and no other.

In one sense, my metaphor of the development of a baby's cognitive functions, or HAL 9000's processing power, is a false one. It implies that movement towards super-organism status will lead to some kind of mega-mind, a planetary gestalt, or even a Gaia-type deity. This kind of claim has been made before by people with more interest in mysticism than science. Yet the emergence of complex organisms in the Cambrian Era did not lead to any new desires or intentions. These alliances of cells continued the struggle for resources and ultimate survival of their genes in the same way countless generations of their single-celled ancestors had done before them. The evolution of eusocial organization in bees, ants, and termites did not lead to the emergence of a deity-like hive entity, nor would we expect it to. The human domestication of plants and animals and the increasing interdependence of the species made all of the members of this partnership much more successful in competing for control of planetary resources. Perhaps an argument could be made that the explosion of human knowledge through collective learning did indeed make us smarter, but I doubt that we are really cleverer today than people 30,000 years ago. Indeed, the human brain seems to have shrunk by the equivalent of a tennis ball over that time. On the other hand, the Cambrian and the preceding

Ediacaran eras did see the evolution of the first central nervous systems, creating necessary functions for centralization and coordination of the collective whole. It is only to be expected that a new stage of complexity would also involve the emergence of appropriate structures of control. Is this, perhaps, the principle role of humanity in this grand alliance?

The Cambrian explosion created unprecedented ways for life to compete for resources and to pass on genes, and a new super alliance of organisms should be expected to continue this trend. The human-plant-animal-bacterial-fungal super alliance has done an impressive job in competing for resources, possibly in the order of 25% to 40% of total energy produced through photosynthesis. That leaves reproduction. Our super alliance is so world dominating that there is no room for another on this planet, but the billions-year-old drive to propagate hasn't disappeared. The drive to expand and colonize first the Solar System and then other stars continues apace. In April 2013 Stephen Hawking called for space colonization in order to avoid species extinction. In the same year 78,000 volunteers signed up for a proposed one-way mission to Mars, a mission to be preceded by unmanned supply drops. In the same way in May 2013 at the Starship Century conference at La Jolla I heard Freeman Dyson suggest that the logical way to colonize planets around other stars would be to first populate them with biological seed-ships (something that he noted would be interpreted as an act of interstellar biological warfare if another species did it to us!) Naturally all colonization efforts would be conducted by humans accompanied by, or even preceded by, most of our plant, animal, and microbial allies. In other words, all efforts are actually heading towards the propagation of the multi-species alliance. Interestingly, this almost exactly corresponds to one of the more puzzling changes created by the emergence of complex organisms in the Cambrian era. A major cost is that the vast majority of individual cells have to be willing to sacrifice their genetic future in order to help a single sperm or egg to reproduce. Every time I think of this, I have a surreal vision of an interstellar colony ship as a single sperm launching itself on an unimaginably long journey in the faint hope of creating a new copy of its parent organism.

I have taken this opportunity of writing for the IBHA newsletter to indulge in some speculation and brainstorming, but I truly do wonder whether we are now in the middle of a process equivalent to the Cambrian Explosion. It began with the first domestication of plants and animals and will continue into the future. Instead of different species of single-celled organisms joining together to form complex organisms, we are seeing complex organisms and microbes joining together into a much larger alliance system. In the Cambrian explosion, most modern animal plans emerged in a short space of time including symmetrical bodies, heads, tails, etc. All subsequent evolutionary processes, even up to and including the development of legs and arms (and thus our own physical structure) involved modifications of forms that came into existence during that far distant period. If we are indeed in the midst of what seems to be the logical next step (when complex organisms form together to become the equivalent of a super-complex organism), then the critical importance of the current era is that we are establishing the shapes and forms that are the foundation for all future structures of super-complex organisms. I suspect that future observers will look back on the current age in much the same way as we look back on the remarkably sudden emergence of complexity during the Cambrian era.

Jonathan Markley is a New Zealander by birth, began his studies at the University of Auckland, then taught history for four years in Hong Kong, before moving to Sydney, Australia, where he earned his Ph.D. at Macquarie University. His first book (sitting with the publisher for more than two years now) is entitled "Peace and Peril, Sima Qian's Portrayal of Han - Xiongnu Relations". He moved to Cal State Fullerton to join the History Department in 2006. He is currently enjoying a sabbatical to work on his Big History of Grass manuscript. The theme of this piece for the IBHA emerged almost by itself as it was being written, and exploring these ideas will be Markley's next major project.

California State University Fullerton

The Life and Works of Antonio Vélez Montoya

Natalia Vélez Lopera
Metropolitan Technological Institute (ITM)

A man with a passion for knowledge and science The first impression of Antonio Vélez Montoya is that he is a man full of happiness and wisdom. When being asked for giving an interview, he claimed not to know how to begin nor which aspects to highlight, a sign of his humility. It is not an easy task to account, in few hours, a story that has lasted 80 years. I asked him to start from the beginning.

Antonio Vélez was born 8th June, 1933, in Medellin, Colombia, when the city was still a small town. He lived in the El Poblado district, at the south end of the city, since he was four years old. From his childhood he remembers playing with his friends and with toys built with his own hands. At that time, all toys were imported and in consequence, they were very expensive, only accessible to rich people. “Batteries were nonexistent, and to make toy cars run you had `to wind up a string´”, he says smiling. He also used to play soccer. El Poblado was a kind of a continuous play ground, “the easiest thing to do was to roll a ball”.

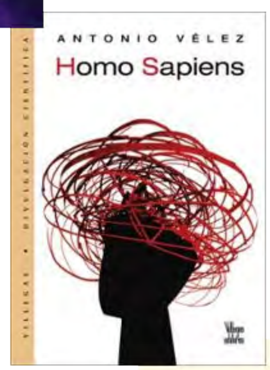
He belonged to a huge family, as was customary at the time. It was formed by his mother, his father and 10 children (6 women and 4 men), plus his grandfathers and grandmothers; in total they were 16 people living together in a big house. Today, he considers this situation inconceivable. He remembers that in order to sit at the table to have lunch, each had to wait their turn in line.

He studied in a school name San Ignacio, which belongs to the Society of Jesus, and he makes jokes remembering that he was graduated in the middle of the last century, just in the year 1950. As he said, “I was a mediocre high school graduate afraid of not being able to study Medicine or Civil Engineering, which were, at that moment, the most prestigious careers. Those majors were in huge demand, so I decided to study Electrical Engineering in Pontificia Bolivariana University”. He assumed it would be easier to enter given that it was a new profession, not as desired as the others. He did not have a particular intellectual goal, he only wanted to find a job. In that time there were no electrical engineers in Colombia; for example, the engineers belonging to the electrical company Empresas Públicas de Medellín (Public Works of Medellin) were actually Civil Engineers. Professor Antonio smiles when he remembers that he never has used his tittle of Electrical Engineering. He does not even know where the diploma is. Perhaps it is hidden in a drawer or a closet. He is thankful that his profession gave him the opportunity to fall in love with Physics and Mathematics. Thanks to the Dean of the Faculty who asked him to teach a course of Descriptive Geometry, he began to teach when he was in his third year of studies.

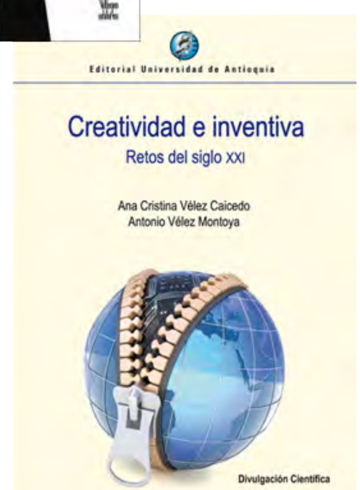
The teacher in charge of the subject had to leave Medellín, and recommended Antonio as his replacement. He said, “In the city of Medellin, we won’t find someone who knows the subject as well as him”. From that moment he has been teaching in the disciplines of Geometry and Mathematics, in Pontificia Bolivariana University first and then in the University of Antioquia. Later, he moved to Cali, to teach at Del Valle University, and finally at EAFIT University in Medellín. He certainly would say that in teaching he found a profession for his whole life. In addition, he likes to study as much as to teach. From his point of view, "a teacher that does not like to study gets bored." He loves to change his subjects of study, and the University gave him the possibility of teaching different courses in the field of mathematics.

Antonio Vélez wanted to be a mathematician and a high school professor. He saw the act of teaching not only as a way to make a living, but also as an interesting field in and of itself. In order to understand the problem of learning math, and how it should be taught properly, he began to practice what he thought: that a good teacher must distinguish those aspects that are more difficult and find various ways to explain them, many times if necessary. Also, he believes that it is important to pause and tell stories, and to challenge the students with beautiful problems to be solved, in order to entertain and delight them. Therefore, Antonio specialized in puzzles and motivation through creative thinking. This interest is reflected in a book written in with his son, Juan Diego, and his daughter, Ana Cristina: *Creative thinking*, published in 2010, and one of his other books: *Creativity and Invention, Challenges of XXI Century*, published in 2013, co-authored with Ana Cristina.

While he was in Del Valle University, he married Maria Cristina Caicedo, also from Medellín, and had three children: Juan Diego, a mathematician, Ana Cristina, in the art world, and Maria Isabel, a geologist. After two years working at Del Valle, he received an offer to return to teach at the University of Antioquia and he accepted, returning to Medellín with his family. For a while he taught and lead the Department of Mathematics as a director, but he found that he did not like administrative work. He loved teaching. Thanks to the support he received from this University, he got a Ford Foundation scholarship in 1965, to study a master's degree in mathematics at the University of Illinois. Two years after he returned to Colombia, the company Coltejer offered him a job in the area of Operation Research and he accepted it. This job, in which he worked for 13 years, allowed him to do research without giving up teaching. He returned to the University of Antioquia as a chief of the Department of Mathematics. At that moment, his life took a major turn when he decided to write his first book.



At the University, a group of teachers met periodically to conduct seminars on different topics. Antonio was invited to join the group to talk about Evolutionary Psychology. He was passionate about the subject of evolution and human behavior. For a long time he had had the desire to write about this subject, but he never passed from writing the first page. Being fifty years old, he considered that writing would be impossible for him, perhaps he didn't have any talent as a writer. However, each week he had to prepare the corresponding subject for the seminar, so, as time passed, each topic of the written text became a chapter of the book. "At the beginning the writing was far from excellent", he comments, "but at least it was a starting point to correct, to expand or to reduce; and in this way, as an obligation, I managed to finish the book that was published in



1992 with the name: *Man, Heritage and Behavior*.

After overcoming the fear to write, he continued working in texts about several topics of scientific divulgation: *From Big Bang to Homo Sapiens*, *From Pi to Pa: Essays Against the Stream*, *Parapsychology: Reality, Fiction or Fraud?*, and *Homo Sapiens*, among others. He has 13 books published, and from his point of view "an almost indeterminate number", of papers in journals, conferences, and nationwide newspapers. Most of the text speaks about man, evolution, and behavior, issues that interest him very much, but he has also worked on other topics such as paranormal phenomena, creativity, and humor from the scientific point of view. He likes to research, and he considers that: "the world before science was closed, poor and uninteresting. The modern world, technological and advanced in science, does not allow scientific illiteracy. If you do not know basic science you cannot participate in the debates, you cannot think clearly about the world, you cannot predict anything, and you cannot govern it".

These are the words of a scientist that loves intellectual exercise. He is always in a permanent search for answers and better ways to transmit them to others.

Medellin, Colombia

CALL FOR PAPERS

INTERNATIONAL BIG HISTORY ASSOCIATION CONFERENCE

AUGUST 6 - 10, 2014

DOMINICAN UNIVERSITY OF CALIFORNIA

SAN RAFAEL (SAN FRANCISCO BAY AREA), CALIFORNIA

TEACHING AND RESEARCHING BIG HISTORY:

BIG PICTURE, BIG QUESTIONS

DEADLINE FOR ***PAPER*** / ***PANEL*** SUBMISSIONS IS FEBRUARY 10, 2014

The International Big History Association (IBHA) defines its purpose as "to promote, support and sponsor the diffusion and improvement of the academic and scholarly knowledge of the scientific field of endeavor commonly known as "Big History" by means of teaching and research and to engage in activities related thereto."

Article 2 of the IBHA Articles of Incorporation.

The theme for the 2014 conference is "Teaching and Researching Big History: Big Picture, Big Questions." The conference seeks to continue the dialog begun at the first IBHA conference in 2012. In addition IBHA seeks to create a forum for the articulation, discussion, and distillation of questions central to Big History. Among the topics that are to be addressed at the conference through a series of panels, roundtables, and discussions are:

- *Big History and energy*
- *Big History in education*
- *Big History pedagogy*
- *Big History scholarship*
- *Big History research agenda*
- *Evolution of complexity*
- *Identification and analysis of thresholds*
- *Continuity and Contingency in our Universe*
- *Big History: interdisciplinary, multidisciplinary, or trans-disciplinary?*
- *Big History and the future*
- *Big History and meaning*
- *Big History outcomes and assessment*
- *Politics and Big History*
- *Little Big Histories*

Along with regular panels and roundtables, presentations might consist of:

- *Question and answer sessions – where Big Historians will be able to answer questions and discuss research questions that are worth pursuing*
- *Brainstorming sessions – with very short, provocative papers*
- *General discussion panels – where different points of view about Big History can be addressed in 5 minute increments, specifically addressing the different cultural perceptions of Big History*
- *Workshops – where participants will view short film fragments and other art forms chosen by Big Historians, and presentations on Big History from the artistic point of view from artists, musicians, and storytellers*
- *Conference roundup – with a keynote address that summarizes the most important things outcomes of the conference*

We encourage proposals on any topic related to Big History. A select group of papers will be included in a compilation of Big History Research that will be published after the 2014 conference.

The time limit for presenting papers will be 20 minutes, and the deadline for submitting papers to the session moderator is three weeks in advance of the conference. Individual paper proposals must include a 250 word abstract with the title of the paper, name, institutional affiliation, e-mail address, phone and fax numbers, and brief curriculum vitae, all integrated into a single file, preferably in MS-Word. Proposals for complete sessions or panels must contain the same information for each participant, as well as contact information and a brief C.V. for the moderator if you suggest one. (The program committee can help find moderators, if necessary.) Please submit your ***paper*** or ***panel*** proposal by clicking on one of these links, which allow for submission information. The deadline for paper and panel submissions is February 10, 2014.

All presenters at the conference must be members of IBHA. Presenters may become members at www.ibhanet.org and will need to do so prior to registration for the conference.

The IBHA Conference will convene on the campus of Dominican University of California in San Rafael, which is located twelve miles north of the Golden Gate Bridge. Attendees will have the option of selecting from one of several hotels in San Rafael and the surrounding area or staying in on-campus accommodation.

San Rafael is a wonderful destination in Marin County surround by woods and beaches. For all things San Rafael go to http://www.sanrafael.com. For a complete guide to San Francisco and its many attractions, visit http://www.sanfrancisco.com/. And if you have more time to explore the larger Bay Area, see http://www.visitcalifornia.com/Explore/Bay-Area/.

Please find more details on the conference at www.ibhanet.org. We hope you can join us for this fantastic second IBHA conference!

Edgehill Mansion, Dominican University of California

Program Committee:
Mojgan Behmand, Cynthia Brown, Lowell Gustafson, Fred Spier, Harlan Stelmach, Joseph Voros, Neal Wolfe

Transportation to/from San Rafael

Flying into SFO
We suggest taking the Marin Airporter from SFO to Marin and disembarking at the Central San Rafael Transit Center. Approximate travel time is 1.5 hours. Buses pick up passengers at SFO every 30 minutes, on the hour and half-hour, beginning at 5:00 AM. The last bus of the night departs from SFO at midnight. Fare is currently $20. http://www.marinairporter.com/schedules_sfo_to_marin.html
From the Transit Center in San Rafael, there are taxis available to take you to your hotel. If you are staying at the Four Points by Sheraton in San Rafael, it is approximately 3.3 miles from the Transit Center to the hotel.

Flying into OAK
We suggest taking the Sonoma County Airport Express to Marin and disembarking at the Central San Rafael Transit Center. Fare is currently $26. Please refer to the Airport Express website for travel times and pick-up times. http://airportexpressinc.com/schedules.php
From the Transit Center in San Rafael, there are taxis available to take you to your hotel. If you are staying at the Four Points by Sheraton in San Rafael, it is approximately 3.3 miles from the Transit Center to the hotel.

Hotel
Four Points by Sheraton
1010 Northgate Drive
San Rafael, CA 94903

Central Reservations 1-800-325-3535
Hotel Reservations 1-415-479-8800

Callers should identify themselves members of “DU-IBHA” arriving on Wednesday, August 6th and departing Sunday, August 10th, 2014 to secure the special rate and receive their confirmation number. Callers should have a credit card ready to guarantee reservation.

Discounted Rate: $114 (by 5pm local time, June 13th, 2014)
Group Rate: $139 (by 5pm local time, July 11th, 2014)

Reservations may be cancelled without penalty up to 24 hours prior to arrival.

Gabri and Sandro invented the concept of “Geofonia” (geophonics, the sound of the Earth) and with their original computer program, christened by them Frankenstein, they can compose music using numerical geologic data, which are normally utilized by scientists to reconstruct events in Earth’s history.

The booklet “Dances with the Earth” explains the concept and techniques of Geofonia, but it is also an accessible popular science essay about stratigraphy and geologic research. The accompanying audio CD contains the first 12 geophonic music pieces composed by Gabri and Sandro using data from research projects carried out at the Osservatorio Geologico di Coldigioco, in central Italy. Gabriele Rossetti studied electronic engineering at the University of Ancona, and worked for three years at RAI (Italian Public Broadcasting) as a sound technician transferring analogic tape recordings of old radio programs to digital support. He now works as programmer at AEA (Advanced Electronic Applications) and has just set up a recording studio in the private multicultural center of Coldigioco. - See more by clicking here.

Please click on each of the 12 songs listed to the right to listen to them.

Remembering Gina about 0.5 nillion years
Crows and seagulls about 1.4 million years
Jazz on the rocks about 1.4 million years
Alla festa del duca about 0.5 million years
Friedrich der zweite *about 1.0 million years*
La vedova del samurai about 0.6 million years
Falaise à la Debussy about 2.2 million years
Jumping sardine about 0.6 million years
Mediterraneo about 1.2 million years
Comets-go-round about 3.4 million years
Across the boundary about 5.2 million years
Waves and layers for Gina about 0.5 million years

Dances with the Earth:

Geophonic Music from the Stratigraphic Record of Central Italy*

Gabriele Rossetti and Alessandro Montanari
Geological Observatory of Coldigioco
Coldigioco, Apiro, La Marche, Italy

The vast majority of us have had the chance to learn some physical science during our school curriculum. You might remember that there are different types of rocks and that they are continuously transformed by geological processes, such as tectonism, metamorphism, erosion, and sedimentation. The relation of one rock layer to another is called stratigraphy, the branch of geology that studies the history of the Earth. In order to truly appreciate "geophonia," or "the sound of the Earth," it is important to explain at least some basic principles of geology, in particular, stratigraphy.[1]

The 4.6 billion year old history of planet Earth has been reconstructed by geologists carefully studying rocks with various scientific and analytical approaches, such as mineralogy, petrography, sedimentology, tectonics, geomorphology, geochronology, geophysics, paleontology, geochemistry, structural geology, and – of course – stratigraphy. Geology is a comparatively young science that began a couple of centuries ago, when James Hutton, in his "Theory of the Earth" (1788), first developed the principle of "uniformitarianism." Hutton surmised that the present surface of the Earth formed in response to continuous and gradual natural processes through time.

Modern landforms were created over a much longer time period than was then thought possible and included such geological processes and phenomena as volcanism, erosion, and sedimentation. These natural processes can be observed acting at present following the same physical rules as in the past. Hence the phrase: "the present is the key to the past."

Hutton's uniformitarianism and gradualism, later championed by Charles Lyell in his *Principles of Geology* (1830) and evident in Charles Darwin's *On the Origin of the Species by Means of Natural Selection* (1859), encouraged new generations of scientists to gather information about the evolution of the Earth. Scientists began to take measurements directly from nature and observe the planet and the living organisms that inhabited it. This was in direct opposition to doctrinal teachings and religious dogmas of earlier centuries.

Through the scientific study of rocks, scientists discovered that the coexistence of particular minerals in an igneous or metamorphic rock provides a precise means to measure pressure and temperature conditions at which that rock formed. Similarly, a fossil or a group of fossils trapped in a sedimentary rock demonstrates the environmental conditions (such as water temperature, salinity, oxygenation, or depth) at which that particular sediment was deposited. The texture of a sedimentary rock reveals the energy patterns in the depositional environment. By comparing sediment sizes in modern depositional systems, we can see that pebbles and cobbles in a conglomerate rock had to be formed under strong transporting currents. Conversely, fine-grain limestone and shale are evidence for carbonate and clay minerals being deposited in a very calm depositional environment.

In short, each rock, mineral or fossil has some story to tell about the past. When you put together lots of the little stories from around the world, you can start to decode the partial history of the planet. This is not an easy task, since different stories are being told at the same time at different places on the Earth. When you start layering the stories on top of each other or replacing one story with another, you are left with incomplete and often biased representation of the past.

Geologically, there is a lot of confusion in the arrangement of rocks on the surface of the Earth because the crust of our planet is constantly on the move. The Earth's crust is broken into plates of rock that move in respect to one other: They collide, deform through faulting and folding, and sometimes even overlap onto one another. The surfaces of the plates that form continents are constantly eroded by rain, glaciers, rivers, wind and waves, continuously reshaping the landscape, from the mighty mountain ranges to endless coastlines. The resulting stories, as interpreted by geologists, in particular by stratigraphers, read more like geologic gibberish than an orderly record of Earth's history. Still, there are a remarkable number of patterns and cycles that have been observed in rocks. These patterns and cycles are quantified by numbers – represented by measurements, concentrations, and ratios. These numbers can be interpreted as musical notes. But let's give you a brief introduction to stratigraphy so you can understand just how remarkable the "record in the rocks" truly is.

The Book of Rocks

Using the example of a diary, let us say that you write down everything that happened to you on a sheet of paper. You write one page a day, another page the next day and then lay it on top of the previous page. At the end of the year you have made a diary of 365 pages, documenting what occurred each day that year. If you want to recall what happened at the beginning of the year, you search the pages at the bottom of the stack. To read what happened in the past few weeks, you have to search the pages at the top of the stack. The stratigraphic record works pretty much in the same way.

As sedimentary rock layers and strata are formed, they are generally covered by newer, younger layers of sediments. When the sediments turn to rock over time, we are left with layers of stratified rocks with the oldest layers at the bottom and the youngest layers at the top. Just like your diary. Each stratum or layer of rock is the physical record of the geologic events and processes that created it. Thus stratigraphy is like reading Earth's diary as it is represented in layers of rock relative to one another. Each story is written by a different process or "geologic author." For example, the record of growth of a volcano is written in volcanic rocks like lava, basalt, andesite, tuff, etc. Similarly, the history of a depositional basin, like the ocean floor, river valley, or lake, is revealed by examining the corresponding sedimentary rocks such as sandstone, siltstone, limestone, marl, or shale.

Going back to our original stack of pages in our diary, imagine that all of a sudden the wind pushes open the window and all 365 pages fly around the room disrupting the order of events. Since we had the foresight to write the date at the top of each page, all we need to do is to reorder the pages according to the date, thus reassembling the original stack back into chronological order. Keeping events in their proper order also allows us to correlate or compare a particular day in that diary with that of a friend of yours who lives far away in a different country, and who is also writing a diary like yours.

Similarly, the Earth's geologic diary is continuously being disrupted and reshuffled by such processes as tectonic deformation (faulting, folding and tilting), metamorphism, erosion and resedimentation. Different pages from different geologic diaries can be seen in quarries, along road cuts, in sea cliffs, on the slopes of bare, rocky mountains, or extracted from cores of rock drilled into the crust. So instead of a single geologic diary with the continuous record of 4.6 billion years of Earth's history, what we have are only bits and pieces of the story, written during a specific period of time at a particular place, and now exposed in a particular outcrop. To make matters worse, the pages in the Earth's geologic diary are not numbered.

Rock layers (strata) do not have dates or page numbers that would allow you to reassemble the history book of the Earth. It is the stratigrapher who, using the rule of superposition, starts to make sense of the bits and pieces of the story and can tell in which direction the date arrow points (what goes on top of what). The basic rule of superposition states that, in any given outcrop of stratified rocks, the younger layers are found atop the older layers. Whether it is an outcrop on the face of a quarry or a drill-hole core, the bottom of a stratigraphic section is older than the top (unless the whole body or rocks is upside down or refolded, but the stratigrapher knows how to determine that).

While this works reliably for the outcrop or stratigraphic section you are looking at now, how can the stratigrapher tell whether this succession of rock exposed in this Italian outcrop is older or younger than a succession of rock exposed somewhere else, say, in Spain or China? The various geologic authors need to assign relative or specific dates to the rock layers in their outcrops so they can be correlated in time to rock layers in other parts of the world. The stratigrapher must now rely on the skills of other scientists in other branches of geology.

The geochemist can date certain volcanic rocks based on the radioisotopic decay constant of certain unstable elements contained in minerals that make up the rock, such as mica, zircon, feldspar, and others. Volcanic eruptions can spread volcanic ash over wide geographic distances. The ash contains datable mineral grains that settle to the ground in sedimentary basins far away from the erupting volcano and become incorporated between layers of sediment. The sedimentary layers may also contain particular species of fossils such as seashells, microorganisms, animal bones, and plants. By dating the minerals in the volcanic ash, using the radioisotope method, we get a rough numerical age in years (or million of years) before our present time for the age of the fossil species contained in the adjacent sedimentary layers.

By correlating fossils with radioisotope-calibrated sections from around the world, stratigraphers are able to construct a chronostratigraphic time scale for the whole Earth's history. The relative ages of fossils can thus be derived by interpolation of the dated levels into a biostratigraphic timescale. In principle, each identified fossil has a known range of occurrence, when it first appears and when it last appears in the timescale. No matter if the fossil is preserved in rocks in Italy, Spain or China, the stratigrapher can assign relative ages to sedimentary rocks based on the chronostratigraphic or biostratigraphic data, showing which way the time arrow points.

There are other stratigraphic tools and analytical techniques that can be used to tell the age of rocks. A very precise one is magnetostratigraphy, which is based on the recognition that the

Earth's magnetic field (polarity) periodically reverses itself. It has been discovered that the north to south polarity of the Earth's magnetic field periodically changes orientation between normal (N – S) and reverse (S – N). The length of time between reversals changes throughout Earth's history. Fortunately, within the sediments, tiny crystals of magnetic minerals, such as magnetite or hematite, align themselves with the Earth's present magnetic field like little compass needles. As the sediments harden and become rock, the magnetic grains remain frozen in that magnetic orientation recording the polarity of that time period including magnetic declination and inclination.

Geologists typically represent normal polarity on a graph as a black interval, with white representing intervals with a reverse polarity. The resulting pattern of alternating black and white bars of different thickness is similar to the barcode you see on commercial products. This alternating thickness measurement is similar to the principle used in the study of tree rings and ice cores. Once the magnetic polarity history of the Earth is identified, portions of the barcode can be correlated with other stratigraphic timescales, and we can obtain the relative age of each reversal by simple interpolation. Since magnetic field reversals occur at the same time everywhere on the Earth, each reversal becomes an infallible and precise timeline that can be used to correlate distant stratigraphic sections of rocks.

When there are no unique fossils, magnetic minerals or datable radioisotopes, another approach is to study the rock's chemistry. The change in chemistry through a sedimentary succession is the basis for chemostratigraphy. Chemical variations in the composition of seawater, as recorded in the shells of marine organisms found in sedimentary rocks, can be used to create a chemically based timescale for marine sedimentary rocks. For example, the isotopic ratio of 87strontium/86strontium ($^{87}Sr/^{86}Sr$) in the world's oceans changes through time – a proportion derived between the strontium released from volcanic and hydrothermal activities at mid-ocean ridges versus strontium released from continental rocks.

If marine volcanic activity increases, the $^{87}Sr/^{86}Sr$ ratio will decrease. Conversely, the $^{87}Sr/^{86}Sr$ ratio in seawater will rise when there is increased erosion on continental plates, due to increased mountain-building and/or increased rainfall, which causes erosion and recycling of old strontium. The mixing time of strontium in the world's oceans is fast (geologically speaking), on the order of 1000 years, so the $^{87}Sr/^{86}Sr$ ratio varies linearly and gradually for long stretches of time. Once a strontium isotopic curve is calibrated against a geochronologic timescale or other stratigraphic markers, the $^{87}Sr/^{86}Sr$ ratio (usually measured to seven significant figures) becomes a precise means to determine a numerical age for a layer.

Just as the strontium chemostratigraphy is a powerful tool for global correlation and age determination of marine sedimentary rocks, other chemical elements and isotopes are routinely used to determine variations in the physical properties of a given environment in a given basin, for instance, for temperature. The ratio of stable isotopes of oxygen contained in fossils directly correlates to the temperature of the water at the time the organisms were living and constructed their calcite shells. This is because the isotope ^{16}O is lighter and more volatile than ^{18}O, and can be released by water more easily through evaporation. Thus, the ratio of $^{18}O/^{16}O$ (usually represented by the function $\delta^{18}O$) serves as a sort of thermometer that tells us the temperature of sea water in a given time and place and in Earth history.

Under normal climatic conditions, there is a stable equilibrium of oxygen isotopes in the oceans, which is regulated by the continuous recycling of seawater as the evaporated water returns to the sea as precipitated rain or snow. However, during cold periods such as the glaciations, there is more of the Earth's water locked up in polar ice sheets and mountain glaciers. Therefore, during these times, the cooler seawater becomes impoverished with the lighter ^{16}O and, consequently, the ^{18}O increases. As a result, an organism that constructed its shell during a cold period has a higher amount of ^{18}O than a similar organism that constructed its shell during a warm period. This differentiation can also be observed in the composition of the rain and snow. Precipitation in warmer tropical regions has a $\delta^{18}O$ that ranges between 0 and –2 per thousand. At medium latitudes, the $\delta^{18}O$ ranges between –8 and – 12 per thousand, while snow has a $\delta^{18}O$ from –20 to –40 per thousand in polar regions.

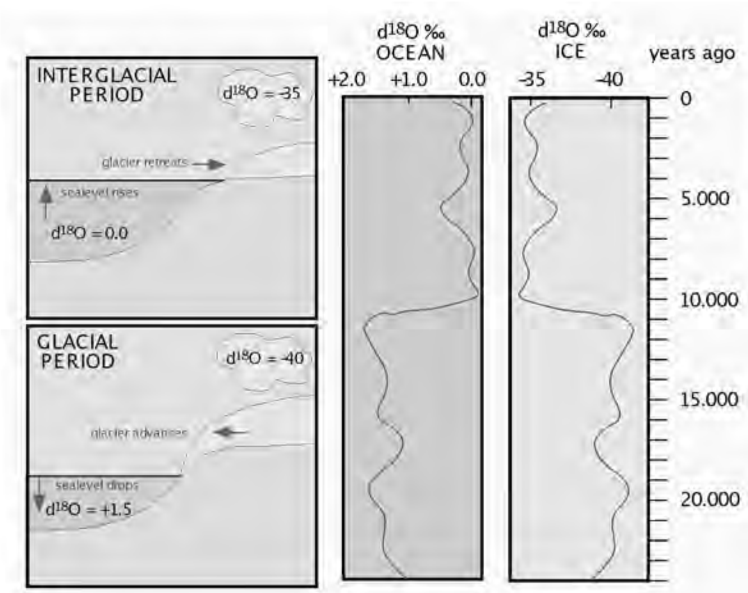


Figure 1: Variations of the $\delta^{18}O$ recorded in see water and ice in the past 24,000 years.

There are many other chemical elements and isotope ratios that are used in chemostratigraphy to characterize sediments and changes in the environment through geologic time. There are also as many other tools such as sedimentology, petrography, quantitative paleontology, and others that can be used by the stratigrapher to decipher the pages of rocks making up the Earth's diary.

Rhythms & Events in Earth's History

After this introduction, it is easy to demonstrate that Stratigraphy is to Earth Sciences as History is to Humanities. Human history has been punctuated by exceptional events, such as wars, revolutions and discoveries that have changed the course of societies and cultures. These exceptional events are separated by periods of "normality," ordinary or routine affairs. While some historical events had global effects, others have affected single countries or societies. In a history book of a particular country, one can read the sequence of events that have affected, through centuries and millennia, the people living there. In the same book, one can also read about major events that have occurred somewhere else but had an effect on that particular country. In summary, human history, in general, goes on through the rhythm of the day-by-day, month-by-month, season-by-season, year-by-year events. However, because of the occasional occurrence of exceptional events, whether good or bad, the course of history is not as uniform or monotonous as depicted by Lyell and other gradualists.

Earth's geologic history works pretty much in the same way as human history. On an evolutionary scale characterized by cyclic events, the planet's history is punctuated by exceptional events, which are used to subdivide geologic time into Eras, Periods, Epochs, and Stages. In human history, the fall of the Western Roman Empire in 476 C.E. is conventionally used by western historians as the boundary between the Classical and Medieval ages. Similarly, the landing of Columbus on a beach in the Bahamas in 1492 C.E. and the consequential colonization of the

Americas marks the boundary between the Medieval and Modern eras.

In geologic history, the boundary between the Paleozoic Era and the Mesozoic Era, 245 million years ago, is marked by a great mass extinction followed by the first appearance of mammals, and coincides also with the breakup of the supercontinent that geologists call *Pangea*. The boundary between the Mesozoic and the Cenozoic Eras 65 million years ago has been correlated to the impact of a giant extraterrestrial object, an asteroid or comet, in the area of Yucatan, and the consequential extinction of the dinosaurs, ammomoids, and other Mesozoic organisms.

In human history there are cycles defined by the alternation of peace and war, abundance and famine, freedom and repression, and so on. There are also cycles that characterize the physical evolution of our planet. Geologists recognize that there is a major cycle in the dynamics of the Earth's crust or lithosphere known as the Wilson Cycle.[2] This cycle is represented by the repetitive disruption and reassembling of continental landmasses, and the consequential opening and closing of ocean basins. The Wilson Cycle can last for hundreds of millions years. Right now, the Atlantic Ocean is in the middle of such a cycle, which started near the Paleozoic-Mesozoic boundary when *Pangea* broke apart, and North America started to drift away from Europe and Africa. In a remote future, at the end of the Wilson Cycle, we may expect that the Atlantic Ocean will close up, and America and Europe will once again be connected along a great new mountain range.

On a local scale, seismic events like earthquakes are also cyclic or even rhythmic. Through time, tension grows in the rock layers in the Earth's crust due to the push or pull of tectonic forces. When the pressures are too great for the rock to withstand, a break or fault will occur and the accumulated tension will be released all at once in the form of an earthquake. After a time, the tension in the rocks starts to accumulate again

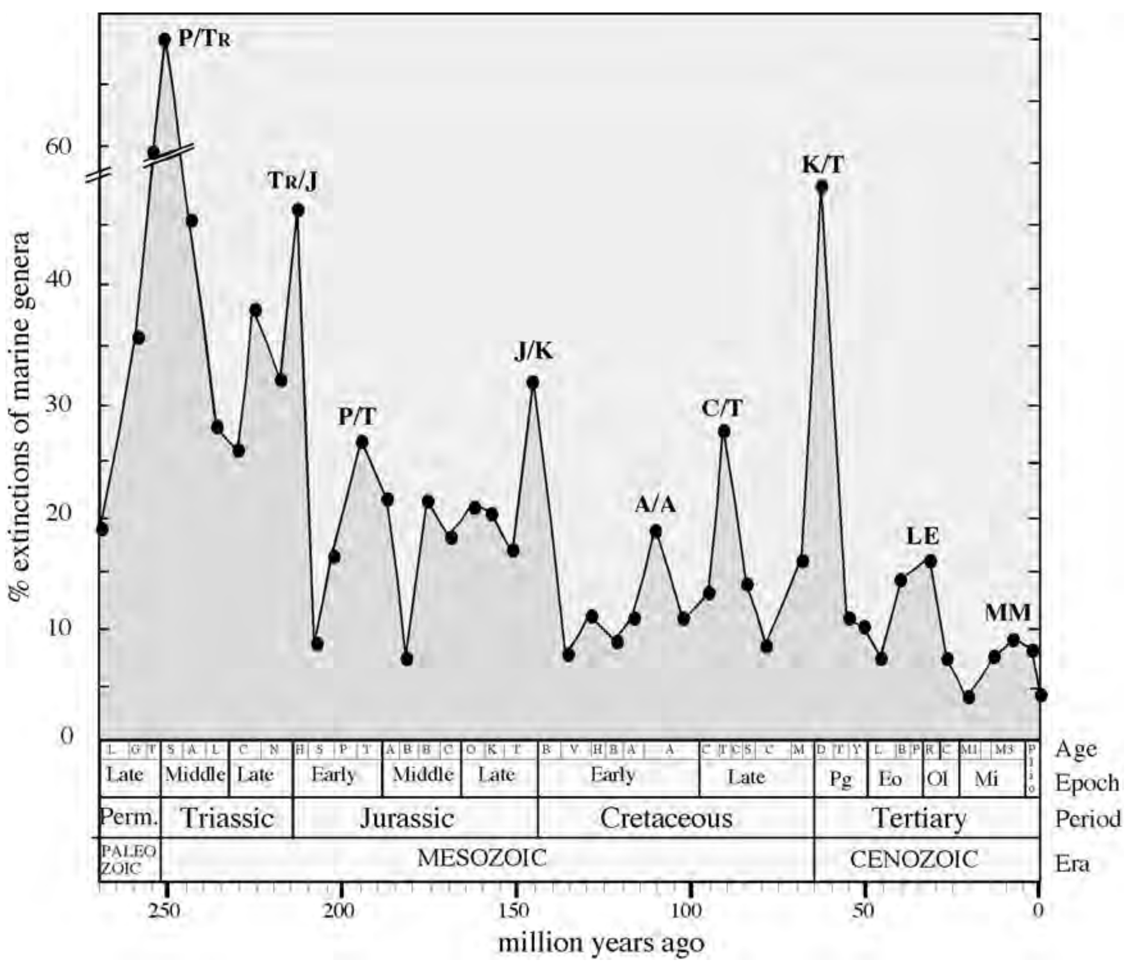


Figure 2: Diagram showing the percentage of marine genera extinctions across interstage boundaries during the past 250 million years (redrawn from Sepkoski, 1996).

until the fault will break again, triggering another earthquake. We know that major earthquakes along the San Andreas Fault occur with a rhythm of about one "big one" every 100 years. In the northeastern Apennines of Italy, the frequency of earthquakes is more likely around 50 ± 20 years. This is due to a different type of tectonic and structural setting between Italy and the Coast Range of California.

There are cycles also in the evolution of life on this planet. Researchers have found that, during the past 245 million years, families and genera of fossil marine organisms experienced major extinction events roughly every 26 million years (Figure 2).[3] In one way or another, these cyclic events are recorded in the sedimentary successions of rocks.

In the case of the Wilson Cycle, for instance, the different phases of opening, expansion and reclosing an oceanic basin can be recognized from the different types of sediments that accumulate. Starting with continental deposits and then shallow marine sediments, the superposition of rock layers is followed by increasingly fine grained sediments, as the ocean expands and deepens. The sequence may start to reverse itself as rock layers of coarser and coarser sediments identify shallower and shallower marine environments, finally regressing from marine to continental sediments as the ocean shuts down.

In the case of earthquakes, the rhythm of seismic events may be recorded by a sequence of sandstone layers alternated with mudstone layers. Every time an earthquake occurs near a coastline, sediment on the submarine slope gets shaken up, remobilized and races down the slope in an avalanche of sediment and water to form what geologists call a turbidity current. The submarine avalanches will eventually lose energy and slow down, depositing their load of sediment on the abyssal plane. The larger, heavier particles settle first, followed by smaller and smaller grain-size particles. The result is a distinctive graded bed of sand called a turbidite. The bigger the earthquake is, then the bigger is the slumped mass and the thicker the resulting turbidite. Between turbidite events, the usual fine-grained abyssal muds are deposited and, after numerous earthquakes, the result is a rhythmic succession of sandstone and mudstone layers. Such a sequence usually shows turbidite thickening-up or thinning-up cycles, which are a reflection of the rhythmicity or periodicity of the tectonic or seismic history of that particular region.

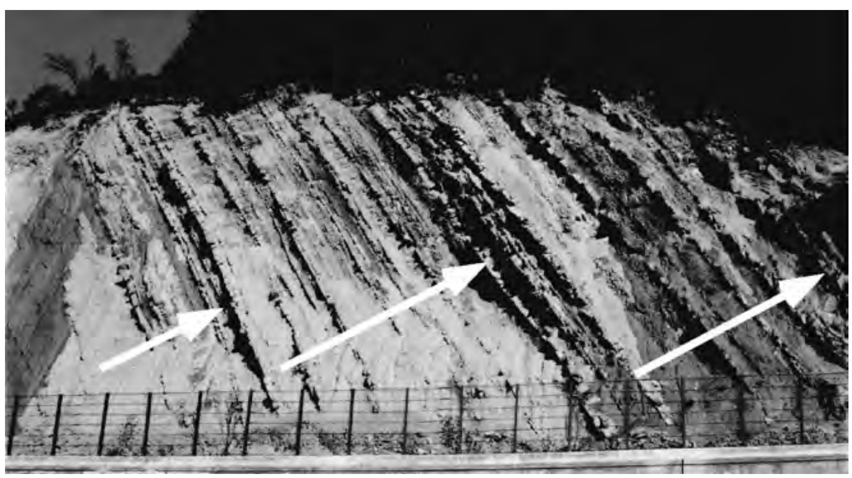


Figure 3: Thickening-up cycles (arrows) of sandstone turbidites interbedded with pelitic marls at the base of the Marnoso-Arenacea flysch formation (Serravallian, about 13 million years ago), exposed along the Contessa Highway near Gubbio (Umbria Region, Italy).

The mass extinction cycles of paleontologists David Raup and Jack Sepkoski are determined by counting out the whole fossil record and determining the percentage of genera or families that went extinct across specific geologic boundaries. The record is derived using a database of fossil occurrences in stratigraphic sections around the world, which have been correlated according to bio-, magneto-, or chemostratigraphic criteria.

In addition to large-scale tectonic cycles (or Raup and Sepkoski's periodicity of mass extinctions) and reoccurring seismic events, sediments are capable of recording cyclic variations of the climate in a given area. For instance, the alternation of dark and light lamina in lake sediments, called varves, reflects the alternation of dry and wet seasons, similar to the concentric rings in a tree stump. Similar cycles are observed in the deep marine sediments far from the impact of seasons and earthquakes. What causes the rhythmic alternation of layers in deep water sediments requires further discussion.

In order to understand deep marine cyclicity, we have to realize that deep marine muds, called pelagic sediments, are formed by the accumulation of tiny shells and skeletons of planktonic organisms that normally live near the ocean's surface. Plankton is most abundant near the surface of the oceans where sunlight can penetrate. This is because the marine algae need sunlight and photosynthesis to live. Other microorganisms eat the algae, which form the base of the entire marine food chain. Many of these planktonic organisms, plants and animal alike, have hard parts made of calcium carbonate ($CaCO_3$) that, after their death, sink to the bottom of the ocean.

With sedimentation rates in the order of millimeters or centimeters per thousand years, these tiny organisms build up huge sedimentary deposits hundreds or thousands of meters thick. Eventually, through compaction, cementation and tectonic uplifting, these deposits become limestone formations making up modern mountain ranges such as the Himalayas, the Alps, and the Apennines. The fact that these limestone formations are stratified (layered) means that the accumulation of planktonic carbonate is not constant through time. Otherwise, we should see only a homogeneous block of limestone with no layering. This indicates that there were climatically favorable times when plankton produced more carbonate, and unfavorable times when they produced less. The result will be alternating layers of stratified rock with some containing more and some containing less carbonate.

Given that most pelagic rock successions exhibit a cyclic or rhythmic organization of layers, and these layers are apparently controlled by cyclic variations of the climate on the order of thousands or tens of thousands of years, the next question stratigraphers face is to identify a mechanism that can explain the observed rhythmic climate changes over such a long period of Earth's history. To do this, the stratigrapher must now go outside the science of geology and talk with other scientists like the astronomers.

The Dance of the Earth

At the beginning of the Modern Era, in Renaissance Pisa (Italy), Galileo Galilei (1564–1642), peering through a homemade telescope, made astronomical measurements that showed the Earth was circling around the Sun and not the other way around. This was at a time when people had been taught, from religious writings and scriptures, that the Earth was the center of the universe. According to Christian scriptures, God created the Earth to host humankind, and accessories like the Moon, the planets and the stars, including the Sun, revolved around the Earth in what is called a geocentric view of the Cosmos.

While Galileo was not the first skywatcher to come up with the idea that the Sun was the center of our planetary system, he came into conflict with Pope Urban VIII, who considered his ideas heretical. Galileo faced the Inquisition, was excommunicated, and subsequently jailed. Under threat of death, he recanted his "heresy," and in doing so regained his freedom. Walking out of prison, Galileo managed to whisper his famous phrase: "Eppur si muove…" (*and yet it moves.*.). And, as it turns out, he was right. Pope John Paul II lifted Galileo's excommunication in the year 2000.

In a choreographic sense, the dance of the Earth around her star, the Sun, is based on a daily rhythm performed over a yearly cycle. It takes a year for the Earth to orbit around the Sun and, in doing so, she performs 365 pirouettes about her axis. This allows the alternation of day and night. However, the Earth's posture is not vertical, but is inclined about 23 degrees in respect to the vertical on the orbital plane, which is a very important part of our story. This inclination is what causes the alternation of the seasons in the hemispheres, which are meticulously recorded by the varves in lake sediments. In addition to this annual dance, ballerina Earth performs movements with much longer periods, some on the order of tens of thousands of years. These are the so-called precession, obliquity and eccentricity cycles (Figure 4).

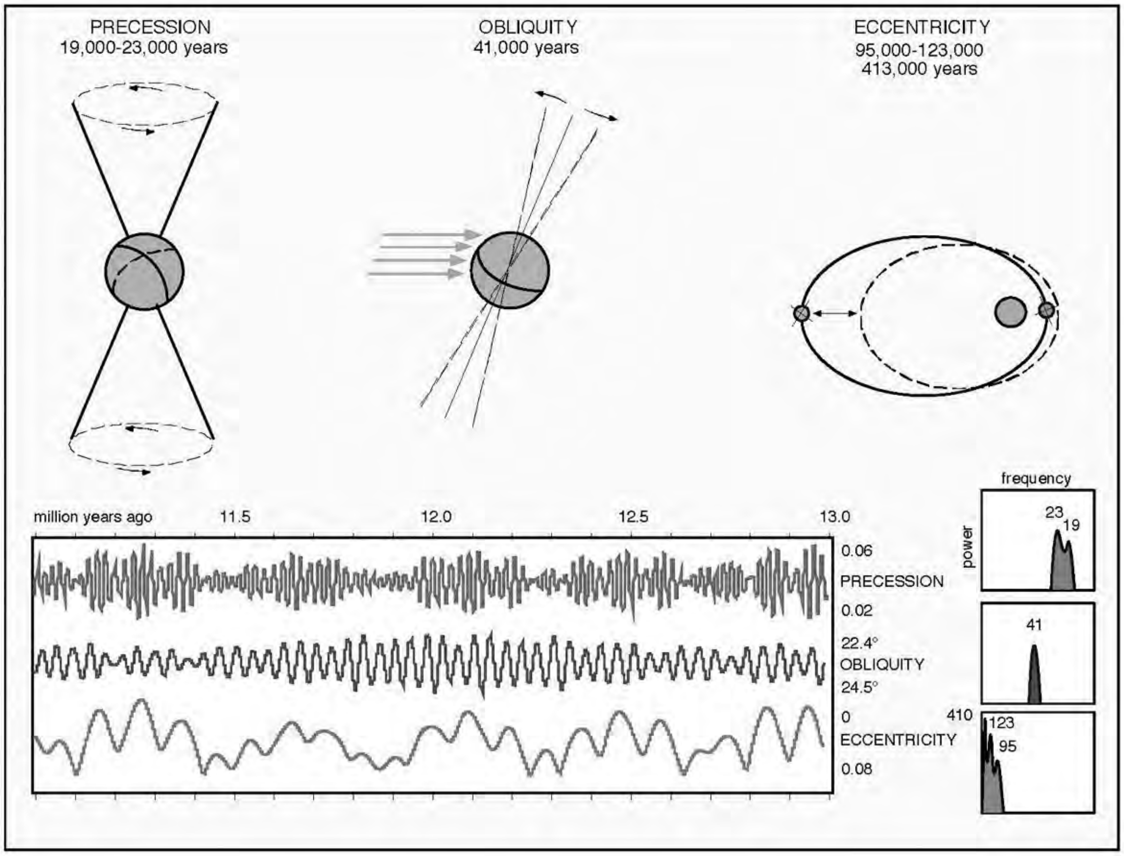


Figure 4: Graphic representation of the Milankovitch cycles, with their relative frequency diagrams and power spectra (redrawn from Portier, 1994).

The precession consists of a wobble in the Earth's oblique axis, which is similar to the movement of a top spinning. In order to complete a full wobble cycle, the Earth takes about 26,000 years. The obliquity cycle is derived from the fact that the inclination angle of the Earth's axis is not constant through time: It moves back and forth by a few degrees during a period of about 40,000 years. Finally, the orbit of the Earth around the Sun is not a circle but rather an ellipse, in which the Sun occupies one of the foci. The shape of the orbital ellipse varies through time from more to less flat, thus from more to less eccentric, with a periodicity of about 100,000 years.

It must be said, however, that the duration of these cycles, which were derived from astronomical observations and calculations, are not “clean” numbers. Statistically, precession has a periodic interference with the elliptical orbit, which varies between extremes of about 14,000 and 28,000 years, with modes of about 19,000 and 23,000 years. The obliquity, which varies by a few degrees, is more likely around 41,000 years. As for the eccentricity, it too seems to be composed by two main cycles, one of about 95,000 years, and the other of about 123,000 years. In addition to these two eccentricity cycles, there is a third one with a longer period of about 413,000 years, and possibly many others with even longer frequencies, which remain somewhat uncertain.

In summary, while performing her dance, the Earth faces the Sun in different postures at every point of her cycles, and finds herself at varying distances from her partner. Knowing this, Serbian astrophysicist and climatologist Milutin Milankovitch (1879–1958) had the insight that varying angles of incoming solar radiation (insolation) on the Earth’s surface (due to the precession and obliquity cycles), and varying distances from the Sun itself (due to the eccentricity cycles) must have major effects on the surface temperature, the duration and contrasts of the seasons at any given latitude, and also on the circulation of aerial and marine currents. In simple terms, there must be an orbital force at work on the global climate of the planet. Thus, Milankovitch (1941) came up with the theory that the Earth’s climate varies cyclically, from warmer to colder, from wetter to dryer, in response to more or less insolation. According to the Milankovitch theory, cyclic variations of the climate are the cause of the glaciations and, consequently, are a controlling factor of the biologic evolution on our planet.

Cyclic & Event Stratigraphy

Prior to publication of the Milankovitch theory in 1941, climatologists like Joseph Adhemar (1842) and James Croll (1875) already recognized the role of orbital forcing on Earth’s climate. Earth scientists like Grove Gilbert (1895, 1900) inferred a relationship between rhythmic stratification and orbital cyclicity. Today, cyclostratigraphy is an important interdisciplinary approach in the study of Earth’s history, one involving ever-increasing numbers of earth scientists. The recognition of cycles in a section of rock may serve as an extremely precise method for calibrating the geologic timescale. High-resolution study of the paleontological record in these cyclic sedimentary successions leads to better understanding of the effects that climate changes had in the biological and ecological equilibrium of a given environment. It also gives insights to the possible consequences that present climate change, accelerated and/or aggravated by human activity, may have on our own environment in the near future, such as

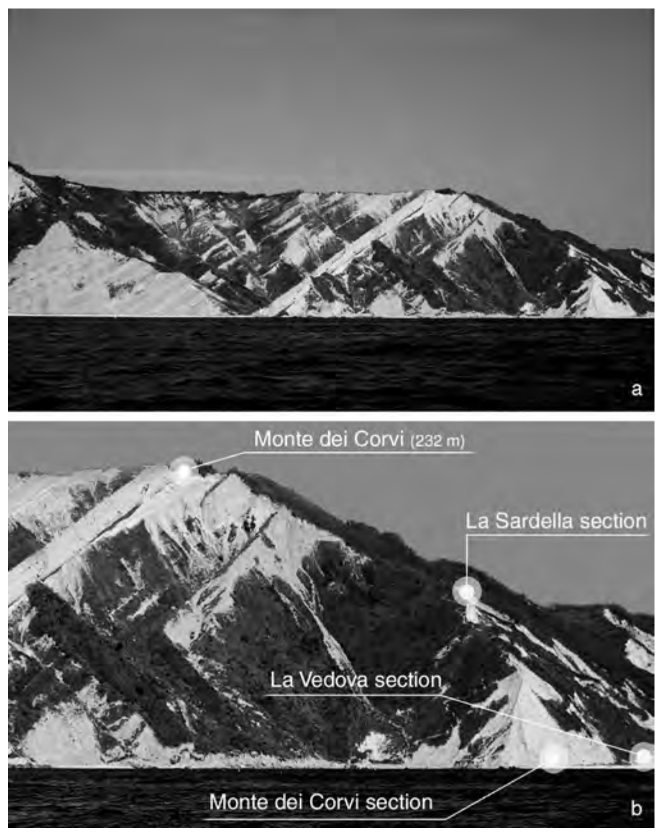


Figure 5: Panoramic view of the Monte dei Corvi cliffs (a), and locations of the studied sections (b).

greenhouse effect, pollution and global warming, changes in atmospheric and oceanic circulation, nuclear winter, glaciation, and desertification.[4] As an example, let's take the pelagic succession exposed along the picturesque Cònero Riviera, near the Adriatic port city of Ancona (Marche Region of Italy).

The Monte Cònero promontory (572 meters high) is an isolated anticlinal fold of the Apennine range, the backbone of the Italian peninsula. The stratified marine rocks making up this relief are extensively exposed along sea cliffs, which represent a natural cross section of the whole anticlinal structure. The oldest exposed rocks of the Cònero sedimentary succession (at the bottom of our book of rocks) are represented by white pelagic limestone formed in the Early Cretaceous Epoch, some 130 million years ago. The youngest in the succession are siltstone, marl and clay layers of Pliocene age, formed about 3 million years ago. One of the last chapters of the Cònero succession is represented by a formation called Schlier, which covers the middle to upper part of the Miocene Epoch, from about 16 million to 6 million years ago.

The most continuous and complete exposure of Schlier is found on the cliffs of Monte dei Corvi (Figure 5 a–b), midway between Ancona and Monte Cònero. The integrated stratigraphy of this section was worked out by a team of interdisciplinary earth scientists who defined a detailed lithostratigraphy and biostratigraphy based on different groups of microfossils, and a chemostratigraphy based on different chemical elements and stable isotopes.[5] Unfortunately, the magnetic properties of these rocks, altered by superficial weathering, are not conducive to magnetostratigraphy. Nevertheless, a few volcanic ashes interbedded with these pelagic limestones and marls permitted direct radioisotopic age determinations, and helped to accurately calibrate the Miocene time scale.

One aspect of the Monte dei Corvi section that strikes the visitor at first sight is the remarkable rhythmic layering of the beds (Figure 6 a–b). The Schlier formation here is characterized by an alternation of hard limestone beds and softer marl beds. The limestone is essentially made of fossilized calcareous microplankton (planktonic protozoans called foraminefera and tiny fragments of calcareous algae called coccoliths) containing a minor amount of very fine silicate debris, like silt and clay. In the marls, the silt and clay component is much more abundant, comprising up to 50–70% of the whole rock. In brief, the apparently rhythmic interlayering of limestones and marls records periods of high plankton productivity alternated with periods of low productivity. Were these fluctuations controlled by climatic changes, in other words, are these variations in plankton productivity a recording of Milankovitch cycles? In order to answer this question, the Monte dei Corvi section has to be represented by numerical quantities, which can be analyzed statistically.

The first thing a stratigrapher does in approaching the study of a section of rock is to produce a detailed lithostratigraphic log. This consists in measuring each consecutive layer, annotating on a log sheet or in a field notebook the thickness of the layer, along with a description of its macroscopic characteristics, such as its color and lithology – for limestone and marl, its consistency – hard or soft, and its internal structures – laminations or fossil traces, *etc*. (Figure 7). With such a log in hand, the stratigrapher can make some educated guesses about whether the apparently rhythmic bedding is related to orbital forces or not. At Monte dei Corvi, what was observed is that the mean (average) bedding thickness is about 32 centimeters in a stratigraphic section where the average sedimentation rate, derived from interpolation between two dated volcanic ashes, is about 32 meters per million years (3.2 centimeters per thousand years). Thus, a limestone/marl couplet (a complete cycle of high/low plankton productivity), with an average total thickness of about 64 centimeters, represents about 20,000 years, which is the mean time range of the precession cycle.

It must be pointed out, however, that a couplet thickness of 64 centimeters is just a rough estimate of average bed thickness – in reality the bedding thickness may vary by as much as ± 20% throughout the section.

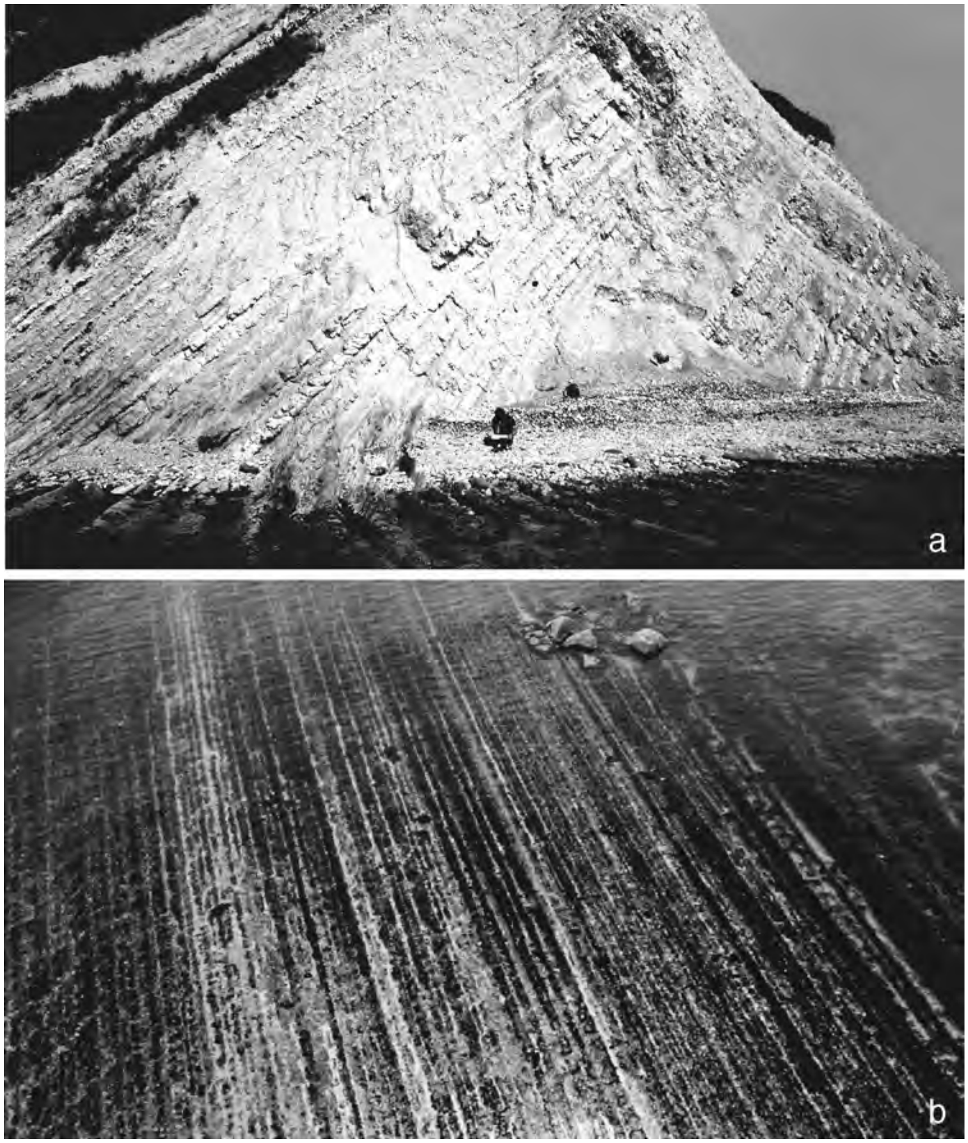


Figure 6: a) Panoramic view of the Monte dei Corvi section near the Serravallian-Tortonian boundary; b) The sea floor in front of the Monte dei Corvi section as seen from the edge of the cliff, down through 1 meter of water, early in the morning of a calm sea. The dark beds making up reefs are actually soft marls, whereas the light beds, which make underwater troughs, are hard limestones. This inversed erosional pattern is due to the growth of algae and black mussels colonies over soft marls. The reef growths in the softer layers are more resistant to wave erosion than the sterile limestones. However, in the outcrop exposed on the cliff, hard limestone beds stick out while softer marls and black shales are eroded. Bedding rythmicity is evident in this image. In the center of the photo, one can actually see a bundle of five limestone-marl couplets representing five precessional cycles (about 20,000 years each) making up an eccentricity cycle (100,000 years). These bundles are visible in other portions of the succession but they get somewhat subdue or even totally lost do to the interferences between Milankovitch frequencies and/or variations in the sedimentation rate.

As a working hypothesis, the stratigrapher can justify this by saying that the whole section records other Milankovitch cycles, like the obliquity cycle of 41,000 years and the eccentricity of 95,000 to 123,000 years. Because these cycles are not exact multiples of each other, they may interfere leading to the formation of beds with different thickness. Moreover, there may have been local factors that could have influenced the plankton productivity, and also human errors while physically measuring the layers in the field.

An effective test for Milankovitch cyclicity requires a more sophisticated statistical approach and a

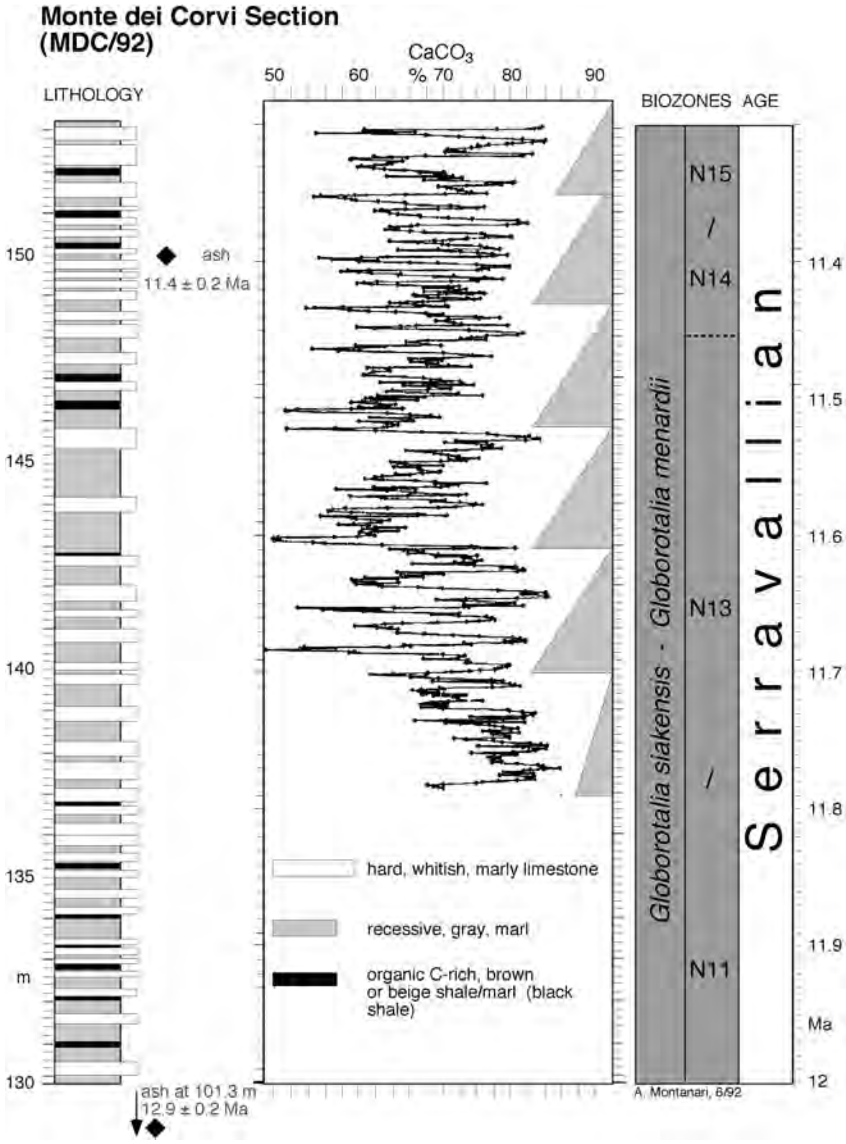


Figure 7: Stratigraphic log of a portion of the Monte dei Corvi section. In the carbonate plot, it is possible to recognize long frequency cycles, which correspond to the 100,000 years eccentricity cycles (gray triangles).

large number of data-points. So, the Monte dei Corvi section is sampled every 2.5 centimeter, and each sample is analyzed to establish the relative abundance of fossilized microplankton as represented by the relative amount of calcium carbonate ($CaCO_3$) in the rock (pure limestone is 100% $CaCO_3$, whereas marl is 50% $CaCO_3$). The result is a curve made of $CaCO_3$ values plotted against stratigraphic height or geochronologic time (Figure 7). Computers using a sophisticated statistical approach, called Fourier transform analysis, then analyze this curve – searching through the data for possible cyclic repetitions of numbers or groups of numbers, and yield a power spectrum consisting of a series of peaks centered at various thickness values (or corresponding time values, which are time frequencies).

The height of the peak in such a spectrum is proportional to the strength (the power) of the cycle. A stratigraphic section with a complete record of Milankovitch cycles will yield a power spectrum with peaks centered in the time ranges of 20,000; 40,000; 100,000; and 400,000 years (Figure 4). The sample quality is determined by geochronologic accuracy, stratigraphic continuity and completeness, negligible local factors or human errors, and high sampling density. The better the recording of a pelagic section is, the clearer is the power spectrum, which could reveal multiple peaks in the precession and eccentricity ranges (Figure 8a).

A more sophisticated way of performing a Fourier analysis, called "moving window analysis," consists in having a window with a fixed width (of thickness or time) sliding through the section. This technique allows you to recognize variations in the power of cycles through time, and/or variations in the sedimentation rate represented by variations and shifts of frequency intensity bands plotted against metric stratigraphy or time (Figure 8b).

There are various techniques that cyclostratigraphers routinely use to prepare quantitative stratigraphic data before a Fourier analysis. A common one is "moving average smoothing." This

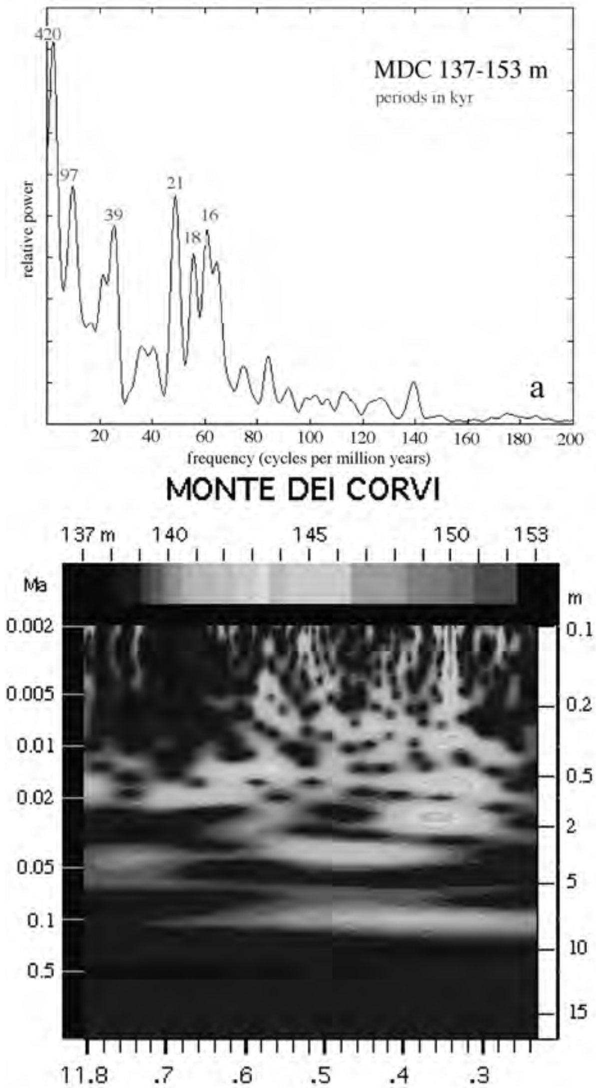


Figure 8: a) Fourier power spectrum of the carbonate (CaCO3) profile through the stretch of the Monte dei Corvi section shown in Figure 7. The main frequency peaks of the Milankovitch cycles are well resolved here; b) Moving window Fourier analysis plot of the same series of data.

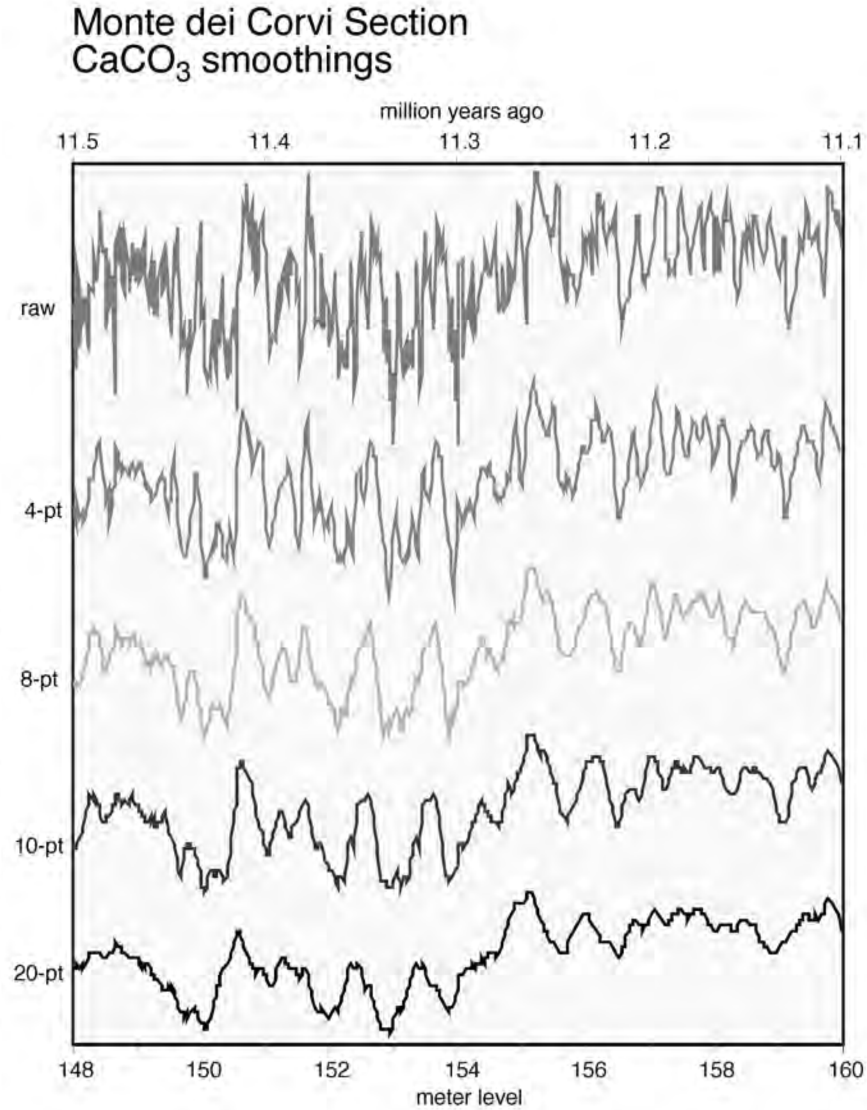


Figure 9: Examples of moving average smoothings in a short stretch of the Monte dei Corvi CaCO3 profile.

consists of having a stratigraphic window of chosen thickness (say 10 centimeter, or four data-points, in our case) and moving it up a section while averaging the four data values. The window moves one step equal to one datum point and plots the average of the four enclosed values. Then it moves ahead by one new point up in the section (thus leaving out the previous point at the bottom of the sliding window), plotting a new 4-point average, and so on, until the window reaches the top of the section. Obviously, being averages, the new plotted points will have values lower than the maximum values originally measured, and higher than the minimum original values. Therefore, the resulting curve drawn through the new points will be a smoothing of the original curve.

Smoothing can be performed on 4-pt, 8-pt, 16-pt, n-pt moving averages, and at each increase of the window width, the resulting curve will be smoother (Figure 9). As the smoothness increases, the high-frequency signals, including noises, will be subdued, and the main cyclic variations will be emphasized, although they progressively lose their intensity.

Therefore, a Fourier analysis of a smoothed curve yields a clearer power spectrum, but will lose some of the spectral detail of multiple peaks.

In addition to $CaCO_3$, there are other parameters that can be used in cyclostratigraphic analysis. The abundance of a particular fossil relative to others, for example, may be an index of environmental conditions, such as temperature or salinity, which varies through time in response to climatic changes due to orbital forces. As mentioned previously, the oxygen isotope ratio in fossil carbonate shells is routinely used as a measure of paleotemperature of seawater, while the carbon isotope ratio is a result of organic matter productivity in seawater. Other chemical elements, or mineral grains, may show cyclic variations in a stratigraphic succession, reflecting variations of the detrital input, which is also controlled by the climate (wet versus dry periods lead to more or less erosion, transport and deposition of fine detritus).

Exceptional events not necessarily related to climatic changes may also show up in quantitative lithostratigraphic, biostratigraphic, magnetostratigraphic or chemostratigraphic profiles, along with other anomalies. For instance, a clay-rich layer in an otherwise carbonate-rich succession may represent volcanic ash. Unusual input of siliceous material may have a positive or negative effect on some organisms, which may be recorded as an increase or decrease in overall population. The same layer would show up with a magnetic susceptibility peak since volcanic material is rich in magnetite grains, or with a maximum of some kind of chemical element, which may be abundant in volcanic ashes relative to biogenic carbonate sediments. Similarly, impact of a large extraterrestrial body like a comet or an asteroid will create a fallout layer fingerprinted by elements common in meteorites but rare in terrestrial rocks.

In summary, the record of events in a stratigraphic succession, whether they are cyclic or not, exceptional or episodic, gradual or sudden, are expressed by numbers in *time-series*. When plotted on graphs and tables, the data has little meaning to the lay person but can be interpreted by trained specialists in many different ways. Here, we simply explain how geologists read the Earth's diary and where our original data comes from. But as you will see and hear, there are other ways to interpret the scientific numbers, as musical notes. This not only allows us to read the diary, but to listen to it and hear the chant of Earth's history.

Sincere Rock

When a ballerina dances, she uses every part of her body, every expression of her face, to interpret a story, a feeling, or an emotion. She uses rhythm and movement, figures and postures, to project the very essence of the story she dances. It is a pleasure for the spectator to watch such expressive grace, impetus, and harmony. Of course, the dancer is accompanied by music, which is also an expression of the same story or emotion. The harmony between the visible movement and the audible music is what makes dance one of the most ancient artistic expressions of humankind. If you see a ballerina dancing without hearing any music, you may begin to actually imagine the music score that accompanies her. The same thing happens when you hear music but see no ballerina, the notes and the rhythm trigger images and emotions in your mind, and the image of a dancer.

In a previous chapter, we talked about the “Dance of the Earth.” The question is: Where is the music? Does anybody hear it? No? Well, don’t feel bad, because even if you had an ear as big as the Solar System, you would not hear a thing while watching the Earth dance. There are no sounds out there in the vacuum of space, and the Earth moves very slowly. And yet, Mother Earth (MoM) is also a very precise dancer. She never misses a chance to write down in stone the choreography of her dance, and the music that only she can hear. All we have right now in the Earth’s diary is a bunch of difficult words and lots of (apparently) senseless numbers.

Scientifically, we can say that music is made up of numbers. The notes are definite frequencies, waves quantified by numbers, produced by a vibrating instrument, and diffused in the air in the form of sound. Since we just said that the Earth writes down her dance and her story in the rocks, and stratigraphers read them and translate them into quantities (numbers), there has to be a way we can extract the Earth’s music from those numbers. What we need is a scientist/musician and a musician/scientist.

And so it came to pass one night during a break, while practicing at Andrea’s house with the band, Alessandro (scientist/musician) asked Gabriele (musician/scientist) the usual let’s-start-a-conversation question:

A - “Hey, Gabri, how do you pay your bills?”

G – “I work at RAI (Italian public TV) in Rome as a sound technician…” and he went back to fiddling with his feedback destroyer that was making lots of unpleasant noises.

A – “Ah… , wow…” and he started to pat the harmonica on his thigh to get something out of it. “…And what exactly…like feedback problems?”

G – “Not really. I reduce into numbers old radio programs recorded on tape, and put them into digital tapes for Mamma RAI’s archive.” At last, the feedback noise quit.

A – “And how do you do that?” And he spat something that came out of the harmonica. Organic, inorganic, he really did not want to know.

G – “I use a computer program that does that. And what about you?”

A – “Well, I am a stratigr… a geologist…”

G – “Earthquakes?”

A – “Not really. I study sedimentary rocks like limestones, sandstones, marls…you know, just to figure geologic things that happened in the past, like millions of years ago. Then I teach students these things and get paid for that. But it’s funny. In reality I too squeeze numbers out of the rock record and put them in an archive where nobody reads them… well…, let’s say that just a few people read them. But… once you have radio programs in digital form, can you read them back and re-hear the original sounds?”

G – “Of course. That’s what they pay me for.”

A – “Oh man! You mean that if I give you a series of numbers, you can get sounds out of them with your program?”

G – “We can try…”

A – “Ok. Why don’t you come over to the Geological Observatory in Coldigioco (OGC) whenever you can, say next Saturday after lunch, and show me this thing?”

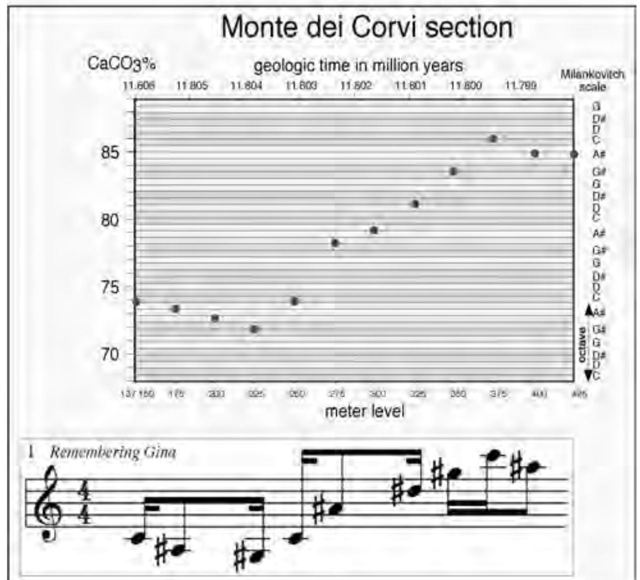
G – “No problem. After lunch Saturday…”. Lins, the singer, tapped a couple of times on the microphone to get attention. “Ok guys. Let’s go back to work. Let’s try ‘La musica che gira intorno.’ Andrea, are you ready?”

The following week, Gabriele drove up to Coldigioco, carrying his laptop computer containing his computer program “Frankenstein.” Frankenstein is the nickname Andrea (the drummer in our band) gave to the program that Gabriele made to easily read time-series. It is so named because his program is a kind of cybernetic monster, made of bits and pieces of algorithmic codes scavenged here and there from the public computer domain, plus things that were actually written by Gabriele. Alessandro then pulled out a floppy disk with a data file that contained some 650 $CaCO_3$ data-points from a 16 meter stretch of the Monte dei Corvi section (equivalent to half a million years of geologic time). This data set was successfully used to test whether this pelagic succession of alternating limestone and marl layers recorded Milankovitch cycles or not, which, in fact it did.[6]

Then, Gabriele started to explain that he could instruct Frankenstein to read those $CaCO_3$ data-points one by one, choosing a scale and a key, like a major scale in C, and starting by playing that note from the first value in the time-series. Frankenstein already contained 11 preordered scales, as shown in Figure 10a. In the case of Monte dei Corvi’s $CaCO_3$ time-series, Gabriele used a modified C minor scale that he called, for the occasion, “Milankovitch” (Figure 10a). Once a scale is chosen, Frankenstein starts by playing the scale key from the first (stratigraphically lowest) datum point it encounters in the time-series. What Gabriele did was to subdivide the range of $CaCO_3$ values into 80 intervals, for example, from a minimum of 50.4% carbonate of clay-rich marl to a maximum of 80.2% carbonate of marly limestone. Each interval would correspond to a key in the chosen scale. At this point, Frankenstein

SCALES	NOTES											
Chromatic	C	C#	D	D#	E	F	F#	G	G#	A	A#	B
Major	C		D		E	F		G		A		B
Minor 1	C		D	D#		F		G	G#			B
Minor 2	C		D	D#		F		G	G#		A#	
Minor 3	C		D	D#		F		G		A		B
Major Pentatonic	C		D		E			G		A		
Minor Pentatonic	C			D#		F		G			A#	
Blues	C		D	D#		F	F#	G	G#		A#	B
Debussy	C		D		E		F#		G#		A#	
Milankovitch	C		D	D#				G	G#		A#	
Arabian	C	C#			E		F#	G	G#			B

a



b

Figure 10: a) The eleven musical scales contained in Frankenstein; b) Graphic representation of how Frankenstein reads and plays a times-series. Once the scale is chosen (in this case a Milankovitch scale), and the whole range of $CaCO_3$ values divided into an arbitrary number of intervals (in this case 80 intervals), the moving bar of Frankenstein reads, from left to right, each consecutive $CaCO_3$ datum and translates it into a note relative to the chosen scale (see also the notes of the music sheet beat). If it happens that 2 consecutive data points fall within the same interval, then Frankenstein will skip the second one.

is instructed to read each consecutive interval at a prefixed steady rate. In this particular case, the 650 or so CaCO3 values are read at a rate of about five data-points per second. Thus, it would be like a reading bar moving up the outcrop at a speed of 12.5 centimeter/second, which is equivalent to about 2560 geologic years/second.

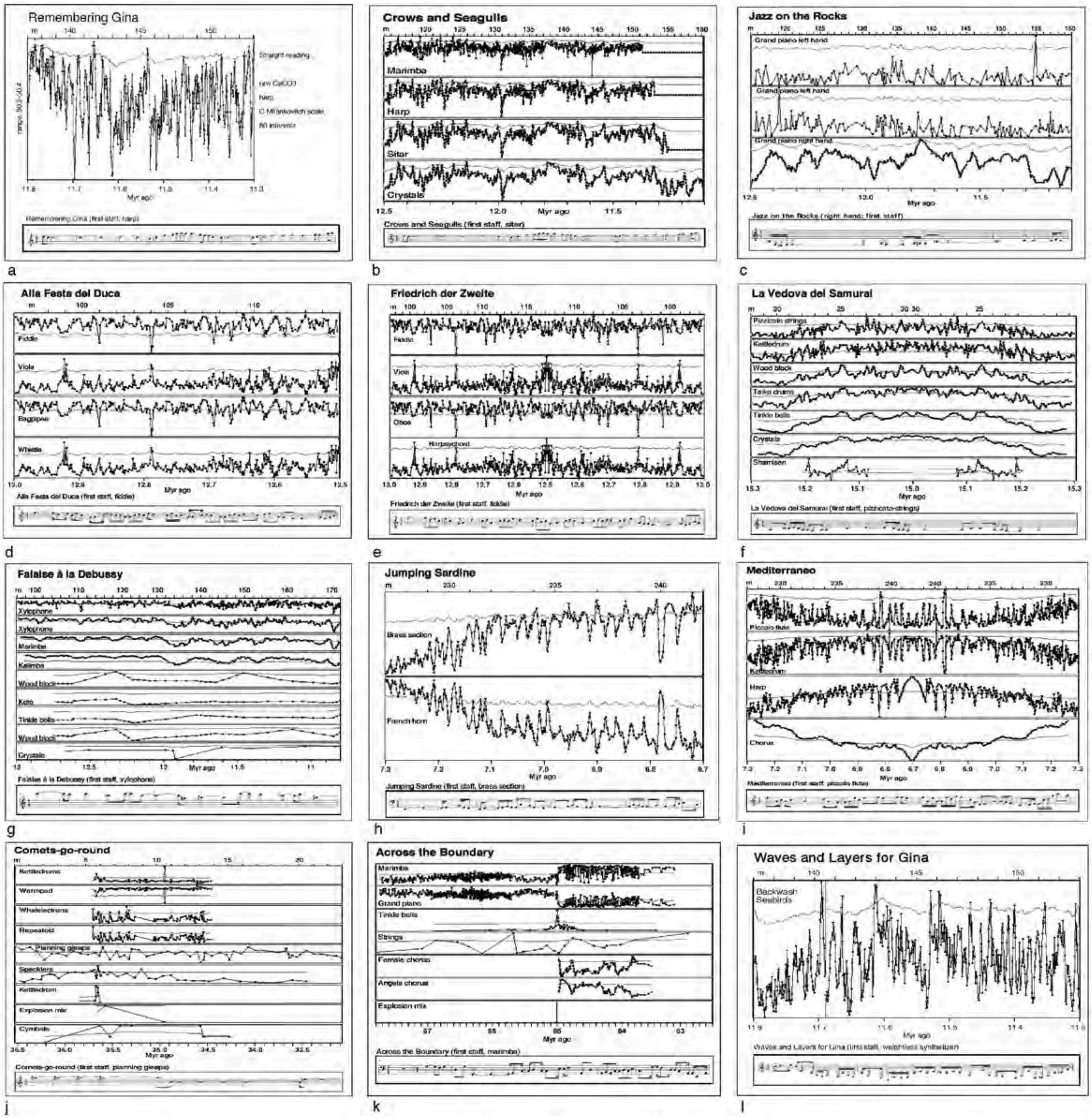


Figure 11: First staff of 12 geophonic scores from the stratigraphic record of the Umbria-Marche Apennines. The complete scores for each geophonic music piece are deposited at the SIAE in Rome. a) Remembering Gina. Straight reading: Harp = raw $CaCO_3$ data; range 80.2-50.4%; 80 intervals; C Milankovitch scale; b) Crows

and Seagulls. All straight reading: Marimba = raw $CaCO_3$ data; range 7.9-96.14%; 72 intervals; C major scale. Harp = 4-pt smoothed $CaCO_3$ data; range 35.65-88.53%; 72 intervals; C major scale. Sitar = 8-pt smoothed $CaCO_3$ data; range 41.23-87.67%;; 20 intervals; C major scale. Crystals = 10-pt smoothed $CaCO_3$ data; range 47.70-85.63%; 12 intervals; C major scale; c) Jazz on the Rocks. All straight reading: Grand piano left hand = raw quartz/calcite data; range 0-3.5; 40 intervals; blues scale in C starting in E. Grand piano left hand = raw quartz/dolomite data; range 0.02-16.83; 40 intervals; minor pentatonic scale starting in E. Grand piano right hand = $CaCO_3$ 20-pt smoothed data; range 55.6-83.68%; 40 intervals; minor scale starting in C; d) Alla Festa del Duca. All straight reading: Fiddle = raw $CaCO_3$ data; range 37.27-92.83%; 30 intervals; C major scale. Viola = raw magnetic susceptibility data; range1.83-18.08 SI units; 40 intervals; C major scale. Bagpipes = flipped $CaCO_3$ data; range 37.27-92.83%; 30 intervals; C major scale. Whistle = flipped magnetic susceptibility data; range1.83-18.08 SI units; 40 intervals; C major scale; e) Friedrich der Zweite. All round trip reading: Fiddle = raw $CaCO_3$ data; range 37.27-92.83%; 30 intervals; C major scale. Viola = raw magnetic susceptibility data; range1.83-18.08 SI units; 40 intervals; C major scale. Oboe = flipped $CaCO_3$ data; range 37.27-92.83%; 30 intervals; C major scale. Harpsychord = flipped magnetic susceptibility data; range1.83-18.08 SI units; 40 intervals; C major scale; f) La Vedova del Samurai. All straight reading: Pizzicato strings = raw 3-pt filling Sr data; range10-88 parts per million; 40 intervals; C major pentatonic scale. Kettledrum = raw 3-pt filling Rb data; range 216-1332 parts per million; 4 intervals; C major pentatonic scale. Wood blocks =10-pt smoothing, 3-pt filling, Sr data; range 13.15-69.3 parts per million; 4 intervals; C major scale. Taiko drums = 10-pt smoothing, 3-pt filling Rb data; range 282.8-1128.3 parts per million; 4 intervals; C major scale. Tinkle bells = 40-pt smoothing, 3-pt filling, Sr data; range 18.1-55.8 parts per million; 2 intervals; C pentatonic scale. Crystals = 40-pt smoothing, 3-pt filling Rb data; range 392.3-1079.8 parts per million; 12 intervals; C major pentatonic scale. Shamisen = raw inorganic carbon data; range 5-15%; 24 intervals; C major pentatonic scale; g) Falaise à la Debussy. All straight readings: Xylophone = raw $CaCO_3$ data; range 21.7-96.1%; 40 intervals; C exatonic Debussy scale; Xylophone = raw 8-pt smoothing $CaCO_3$ data; range 45.6-85.2%; 40 intervals; C exatonic Debussy scale. Marimba = raw 16-pt smoothed $CaCO_3$ data; range 51.6-84.4; 40 intervals; C exatonic Debussy scale. Kalimba = raw 36-pt smoothed $CaCO_3$ data; range 55.6-83.7%; 40 intervals; C Arabian scale. Woodblock = raw Mn, 3-pt filling data; range 280-3279 parts per million; 40 intervals; C exatonic Debussy scale. Koto = raw Fe, 3-pt filling data; range 534-2168 parts per million; 40 intervals; C exatonic Debussy scale. Tinkle bells = raw Sr, 3-pt filling data; range 1502-5986 parts per million; 40 intervals; C exatonic Debussy scale. Woodblock = raw Mg data, 3-pt filling data; range 990-1981 parts per million; 40 intervals; C exatonic Debussy scale. Crystals = raw $^{87}Sr/^{86}Sr$, 3-pt filling data; range 0.708766-0.708951; 40 intervals; C exatonic Debussy scale; h) Jumping Sardine. All straight reading: Brass section = raw pixel brightness; range 61-248.9; 40 intervals; C major scale. French horn = flipped raw pixel brightness; range -0.86-187; 40 intervals; C major scale; i) Mediterraneo. All round trip reading: Piccolo flute = raw $CaCO_3$ data; range 5.5-88.8%; 40 intervals; C major pentatonic scale. Kettledrum = flipped raw $CaCO_3$ data; range 5.5-88.8%; 4 intervals; C major pentatonic scale. Harp = flipped raw pixel brightness; range 97-250; 40 intervals; C major pentatonic scale. Chorus = 40-pt smoothed pixel brightness; range 125-240; 40 intervals; C exatonic Debussy scale; j) Comets-go-round. All straight reading: Kettledrums = raw Ir data; range -4.3-330 parts per trillion; 40 intervals; C blues scale. Warmpad = flipped Ir data: range 0-334.3 parts per trillion; 40 intervals; C blues scale. Whalelectrons = raw Fe data; range 0.736-2.469 parts per thousand; 40 intervals; C blues scale. Repeatoid = raw Cs data: range 1.594-4.373 parts per million; 40 intervals; C blues scale. Planning gleeps = raw $CaCO_3$ data; range 50-80%; 40 intervals; C blues scale. Specklers = raw extraterrestrial ^3He flux; range 0.043-0.541 10^{-12} cc STP/g; 40 intervals; C blues scale. Kettledrum = raw Ir data (Clymer, 1996); range 40-200 parts per trillion; 5 intervals; C blues scale. Explosion mix = flipped Ir anomalies > 100 parts per trillion (Montanari et al., 1992); range 0-232.4 parts per trillion; 8 intervals; C blues scale. Cymbals = volcanic ash thickness; range 2-5 cm; 3 intervals; k) Across the Boundary. All straight reading: Marimba = raw $CaCO_3$ data from Zumaya; range 23.6-96.5%; 40 intervals; C major scale.

Grand piano; raw magnetic susceptibility data; range 4.8-111.2 SI units; 40 intervals; C major scale. Tinkle bells = raw Ir data from Gubbio; range1.8-252 parts per trillion; 12 intervals; chromatic scale. Strings = = raw extraterrestrial ^{3}He flux; range 21-160 10^{-15} cc g^{-1}; 40 intervals; C major scale. Female chorus = flipped, raw 20-pt smoothing, Tertiary $CaCO_3$ data from Zumaya; range 10.7-30.2%; 12 intervals; C blues scale. Angels chorus = raw, 20-pt smoothed magnetic susceptibility data from Zumaya; range 39.5-66.9 SI units; 12 intervals; C blues scale. Explosion mix = Ir anomaly peak at Gubbio; range 1000-3000 parts per trillio; l) Waves and Layers for Gina. Straight reading: Waightless synthesizer = raw flipped $CaCO_3$ data; range 80.2-50.4%; 80 intervals; F major second grade scale. Backwash on smoothed dynamics curve; Seabirds on background.

When the moving bar of Frankenstein hits a CaCO3 value, it will play a key relative to that interval. As the CaCO3 goes up, Frankenstein will play a key higher in the chosen scale. Conversely, it will play a key lower in the same scale. In order to avoid repetitions like ta-ta-ta-ta-ta, Frankenstein will not play two identical, consecutive values (rare in geology) or two values found in the same interval, but will pause instead. Finally, Gabriele used Frankenstein to assign an instrument to the composition from a sample of some 200 instruments and sounds stored in his computer.

For this first attempt, Gabriele chose a harp, simply because it has lots of strings and octaves. So Frankenstein becomes a computerized musician that, instead of reading a music sheet, reads stratigraphic data from a rock outcrop (Figure 10b).

The sound coming out of Frankenstein was not bad at all (see…or better, listen to "Remembering Gina"). It was actually a pleasant kind of melody, and we realized at once that what we were hearing were melodic cycles of the Dance of the Earth.

A – "Wow! Gabri, that's so very cool! Did you save it?"

G – "Well, for now it's saved as an MP3 file but I still have to teach Frankenstein to save the actual parameters and instructions…"

A – "OK, man, let's do more. We have 4600 million years worth of rocks to play with!"

Ironically, only later did we come to understand the real etymological meaning of the word "Frankenstein." It comes from the German word, *Franken*, which means "sincere," that "speaks the truth," and *Stein*, meaning "rock." Ergo: *sincere rock*.

Canons & Techniques

Following the suggestion of Nicholas Kruge, a young musician from Carbondale, Illinois (USA), and son of Michael, an organic geochemist (and musician) who worked in the Monte dei Corvi section, we decided to call what we just did "Geofonia," the *sound of the Earth*.[7] However, we realized that we had to decide upon and respect a certain consistency when composing geophonic pieces with Frankenstein. In essence, music itself is based on rules, called canons, and techniques to perform them. There are notes (numbers) and scales (made of 12 consecutive notes), and there are ways to compose music with them. Then, of course, there is the choice of the instrument(s), the dynamics of execution, such as *piano* or *forte*, the speed of performance, *etc*. Composers practically assemble matrices of notes and play them by respecting some kinds of canons. If they do not like the music that comes out of all this, meaning that they are not satisfied by the musical rendering of their feeling, emotion or imagination, they work on the matrix, change things around, and try again.

The difference with Geofonia is that the numbers are already there, preserved in the rock, and they cannot be changed (that would be cheating). Nevertheless, we do have the ability to decide how to read and interpret them, yet always striving to maintain their original expressive integrity. Besides the subjective choice of scale, starting note, instrument, speed of data reading, volume and interval subdivision, we experimented with a few simple musical techniques that need to be explained. By all means, these are not all the possible ways to interpret stratigraphic numbers and successions, but they are the basic ones we used to compose the pieces in that first experimental geophonic CD.

Skipping

As explained above, this is the suppression of the second of two consecutive and identical notes found in the same interval. It's a rare occurrence in geology, and serves merely to avoid a repetitive "broken-record" kind of sound.

Smoothing

Like routine cyclostratigraphic analysis, smoothing data can be used to produce several tracks out of the same time-series of data. Despite smoothing, variation and/or cyclicity of values is maintained, although their intensities are progressively lowered with increasing width of the moving averaging-window. The result is a series of parallel, more or less smoothed tracks that can be played harmonically with different instruments.

Flipping

This is like producing a mirror image of a set of stratigraphic data and is done by "flipping" the time-series horizontally about the timeline, or multiplying the stratigraphic values by (–1). The data variations remain unchanged in location and relative intensity, but Frankenstein will play the note sequence of the chosen scale according to increasing values on the original track, and backward on the same scale through the flipped track.

Straight, Reverse & Round Trip Reading

We call it *straight* reading when Frankenstein is instructed to read a stratigraphic section from the oldest layer up to the youngest and *reverse* reading when it reads the data from the youngest layer downward to the oldest. A *round trip* is when Frankenstein reads the data upward through a section and, once it has reached the top, it returns down to the base of the section, reading the data in reverse.

Filling

This technique is perhaps the closest thing to geophonic cheating. We used it in a couple of experimental pieces to fill in a stratigraphic profile that had sparse sampling. Basically, filling consists of creating “dummies” between widely spaced data-points by averaging two bracketing sets of real data. In other words, it is an interpolation between 2 data-points, which creates one or more intermediate averaged points (1-pt filling, 2-pt filling, 3-pt filling, n-pt filling). Filling maintains a sustained rhythm and a certain length of execution; it does not alter the original shape of the data profile or melodic cyclicity.

Dynamics

To add some dynamics to a geophonic piece, we produced a strongly smoothed curve for each data set (per each instrument or sound), and Frankenstein reads that smoothed curve in terms of loudness (see the red line in the figures showing the graphic synthesis of each geophonic piece).

As for the rhythm of a geophonic piece, the one that can be heard from the tempo of the execution of the notes is given automatically by the spacing of the original stratigraphic data and the speed of the moving bar. If the data is evenly spaced through a stratigraphic section, then the notes will seem like they are following a regular rhythm, with occasional 1-note pauses due to *skipping*. Otherwise, there will be no apparent rhythm. If the section records cycles, thus some sort of rhythm, Frankenstein will emphasize it with a waving melody, made up of consecutive notes that increase and decrease according to data values.

Geophonics from the Italian Stratigraphic Record

All twelve musical compositions in our CD were derived from ongoing research of stratigraphic sections of rock layers found in central Italy. Their first staff scores are shown in Figure 11a–k. The order of the compositions follows the original sequence of geophonic experiments that we carried out, based on field investigations that had been conducted over several years by students and researchers from various scientific institutes around the world in cooperation with Alessandro Montanari at the Coldigioco Geological Observatory. Now we will briefly explain the geologic history of the stratigraphic sections used and the general geophonic techniques used to read the music in the rock.

{For discussions of each of the 12 musical pieces, please **click here**.

For the entire article, please **click here**.}

Conclusions

In working on this first geophonic CD, we definitively realized that we were making music in a Franco-Anglo-Saxon-Slavish sense. We find it interesting that in several major languages in the world, the verb *to play* means *to make music with an instrument*, but it also means *to have fun*, as with a game. In French it is *jouer*, in German *spielen*, in Russian *igrat*. In Italy, people do not play instruments as though they were having fun with them. They say *suonare* an instrument or a melody, which means “to make a sound” with an instrument, and *giocare* for “to play” with cards or toys. Ironically, Coldigioco translates literally as “hill of game,” or “hill of playing.” But then, in this country – famous for its melodies and *canzone* – you can *suonare* a doorbell instead of ringing it, which is kind of a demeaning form for the verb of music. In passionate *caliente* Spain you do not even make a sound out of an instrument: the proper verb is *tocar*, which means to touch. So, in Spain, you touch an instrument respectfully to make music.

So, what is Geofonia? Well, we think it is just a fun *game to play* and perhaps a way to get closer and *touch* the soul of MoM. We were simply having fun playing *sincere rocks* with Frankenstein, which is after all a humble, obedient instrument!

(Endnotes)

1 This article is a reconfiguration of the book, *Dances with the Earth*, which is an updated edition of the Italian edition, *Balla con la Terra*. The book and CD may be purchased from the Écoles des Mines (http://www.pressesdesmines.com/sciences-de-la-terre-et-de-l-environne). The Osservatorio Geologico di Coldigioco may be contacted at Coldigioco 4, 62021 Apiro, Italy or through (sandro.ogc@fastnet.it).

2 Wilson 1976.

3 Raup and Sepkoski 1982. Sepkoski 1996.

4 To learn more about analytical methods and techniques of cyclostratigraphy, we suggest the collection of papers in Fischer and Bottjer 1991.

5 Montanari and others 1997.

6 Herbert and others 1992. Goese 1999.

7 Kruge and others 1994. Montanari and Kruge 1995. Rossetti and Montanari 2001a.

8 As described in Montanari and others 1997 and Goese 1999.

9 Michl 1996.

10 The study of the Monte dei Corvi section was started by Tim Herbert and others in 1992, later developed by Sarah Goese in 1999, and expanded by Jon Jensen, another Carleton-OGC student who collected an additional 1200 samples from the same outcrop. Jensen 2000.

11 Tateo's samples came from the same stretch of the Monte dei Corvi section studied by Jensen.

12 The $CaCO_3$ data, from samples taken at 2.5-centimeter intervals, were processed using Fourier transform analysis by Goese 1999 and Jensen 2000.

13 Cleaveland 2001.

14 Montanari and others 1997.

15 Gattacceca 1995.

16 Mader and others 2001.

17 Mader and others 2003a.

18 Mader and others 2003b.

19 Montanari and others 1997.

20 Cleaveland and others 2002.

21 Hilgen and others 2003.

22 Montanari and others 1997.

23 Dercourt and others 1993.

24 Montanari and others 1997.

25 Portier 1994.

26 Alcivar 2000.

27 Hut and others 1987.

28 Premoli Silva and Jenkins 1993.

29 Premoli Silva and others 1988. Montanari and Koeberl 2000.

30 Montanari and Koeberl 2000.

31 Montanari and others 1993.

32 Montanari and Koeberl 2000.

33 Clymer and others 1995. Pierrard and others 1998.

34 Alvarez and others 1980.

35 Smit and Hertogen 1980.

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For discussions of each of the 12 musical pieces, please **click here**.

For the entire article, please **click here**.

Detailed stratigraphic studies of Cretaceous black shales from many parts of the world indicated two oceanic anoxic events, one at the Cenomanian-Turonian boundary, sometimes called the Bonarelli Event.

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