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Environmental geophysics

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Welcome readers to this issue's column on geophysics applied to the environment. We have a slightly unusual piece for you this month – something that came across my desk that was just too intriguing not to present. Antonio Menghini, a geophysicist working with the Aarhusgeo group in Italy has been converting EM data into music, possibly initially to see if the data could be interpreted this way, but then as a tool to help explain geology and geophysics to a wider audience. Ultimately the sounds that he and his group of musicians are producing, based on the raw data, are mesmerising - at least to me.

As I read about this concept I found a few more websites that included examples of EMusic by Antonio and his group: (1) sounds from the First Break story referenced below: https://soundcloud.com/eagepublications/sets/what-is-the-sound-of-the-earth-first-steps-into-emusic; (2) some of the presentation (in Italian mostly) of the Viterbo concert described here: https://www.youtube.com/watch?v=sjnoDX-M0Fg; and (3) sounds from a dinner party at the Russian Minex Conference in 2016: https://www.youtube.com/watch?v=UeUD5sDUXNo.

I thank Antonio for his interesting work, and encourage you all to check it out.

Here is Antonio's story:

Jammin' with the Earth

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'Travertines sound like a diminished E chord, while diatomites like a B13 one': these observations come from our experiment with EM data called EMusic, a scientific-musical project born in Italy a couple of years ago. The idea is simple, to transform the raw data collected using a Transient ElectroMagnetic (TEM) system into musical notes (Menghini and Pontani 2016, Menghini 2016). It's only a question of numbers, the trick is to distribute the wide dynamic range of the TEM data to a smaller range of audible frequencies. It follows that we can actually extract musical 'information' that reflects the effective geological setting and that any site has its own soundtrack - that is a 'soundscape,' the audio component of a landscape.

The power of the project is essentially didactic, as it allows us to explain in a funny way, and to a wide audience, complicated phenomena like the EM propagation into the Earth. At the same time, by looking at (listening to?) the data in a different way perhaps we can enhance our understanding of the underlying geological and natural heritage. For this reason, our group is starting a project with a number of Italian schools to expand EMusic - as EMusic can be the gateway to talking about and understanding local geology, paleogeography, geophysics, natural risks, earthquakes, landslides, music, improvisation and musical composition - all in one!

Let me show you a practical example, coming from the EM concert we gave the last summer in the ancient Roman theatre of Ferento, close to Viterbo, Central Italy (Figure 1). During this concert my role as the 'master of ceremonies' was to introduce the tracks, preparing the audience for what they were going to hear – combining information about the geological background of each layer, the geophysical response and how these combined to produce the music. We collected data near the concert location – a site that is notable both archaeologically as well as geologically - and the first composition, called 'Descensus', is based on the direct sonification of the transient collected over the archaeological site (Figure 2). The audience was able to experience a journey into the Earth by riding the eddy currents produced by the changing EM field. It is not only a journey in geological space, but also in time, as we are exploring by means of music, older and older geological formations.

The progressive decrease of the signal translates into playing lower and lower tones. In order to make audible the single pitches in real time, we applied a time expansion factor of 1 million (hence 1 second of music corresponds to 1 microsecond of geophysical data). This first composition allowed me to explain how the TEM method works, going into the technical details of the instrumentation in a simple way. I explained how a geophysicist can model the subsurface by comparing the decay rate of the transient with the interval between pitches (tight intervals for conductive layers and wide ones for the resistive units). The 1D model of the data shown in Figure 3 shows, in a simple way, how the resistivity of each individual formation influences the propagation of the signal: the pitches are grouped closer in the less resistive diatomites and clays, while they are more separated in the resistive travertine/volcanic units and in the sand/conglomerate units.

During the second composition 'Ascensus' the musicians began to interplay with the pitches provided by the Earth: we

Figure 1. *EMusic concert, summer 2017 in the Ancient Roman Theatre of Ferento, near Viterbo in Central Italy.*

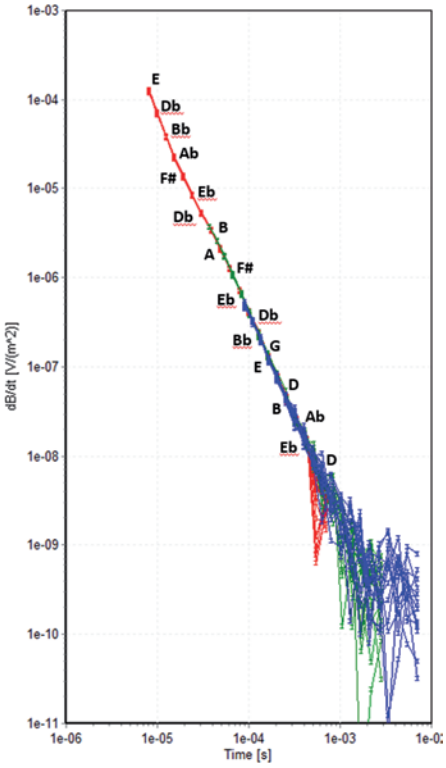

Figure 2. *Raw TEM data from the Ferento site, with notes assigned.*

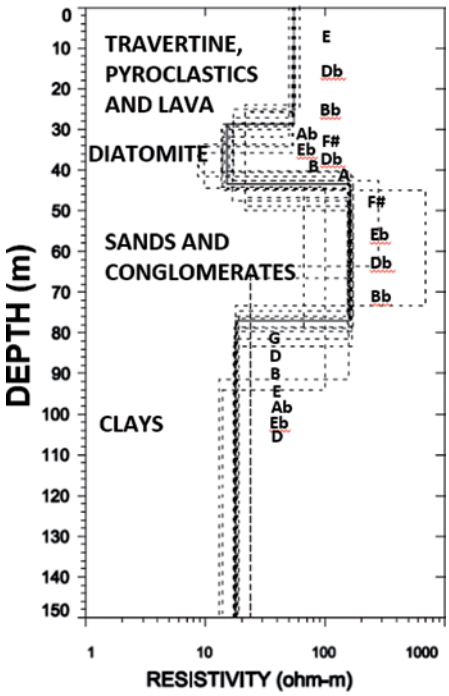

Figure 3. *1D inversion of TEM data, with musical notes assigned – used as the basis for the various musical compositions presented during the EMusic concert in Ferento.*

reversed the first track so that people listened to the return from the maximum exploration depth (in this case about 100 m) to the surface. The saxophonist and the guitarist were able to improvise over the EMusic base, by using the same pitches, in a sort of natural jam session, where the Earth is the band leader.

Then, we analysed each geological formation, by exploring the musical mood provided by the 'raw data's' relative pitch at each layer. For the first interpretive track 'Voltumna' I explained to the audience about the deposition of a shallow travertine layer by the thermal waters that were first used by the ancient Romans (a beautiful spa was excavated in the area, Figure 4). Interestingly the local travertine is the same material that was used to build the theatre where the performance was held (Figure 5). But the thickness of the travertines at the survey location is so thin that the travertine signal does not last long and the pitches quickly reach the underlying volcanic rocks. This area was the site of recent, intense volcanic activity (between 150 000 and 300 000 years ago), in fact the most recent eruption of the Vulsini Volcano

(the Montefiascone apparatus) that our signal flows through. This gave me the opportunity to talk about pyroclastics and lavas and about volcanism in general. A funny musical comment: the three pitches extracted from the travertine-volcanics formation, happened to have formed a diminished chord. In music diminished chords are said to generate a dramatic/mysterious mood, suggesting a sense of irresolution and restlessness. Of course, it was a little lucky that it turned out this way, but we can nevertheless enjoy a nice agreement between the geological scenario and the musical footprint.

The next track 'Elephas Antiquus' was really appreciated by the children attending the concert, because I talked about the presence in this area (about 300 000 years ago) of African fauna, including ancient elephants, hippos and lions, as seen in the rich fossil deposits found in this layer. The Paleontological Museum of the University La Sapienza in Rome holds a beautiful specimen of *Elephas Antiquus* that was found close to Ferento (Figure 6). During this period the area was characterised by the presence of lagoons and swamps, where many of these animals were trapped in the (dangerous) fine clays. This composition allowed us to talk also about climatic changes. It's really curious to verify that the pitches extracted from the diatomaceous clay sound like a B13 chord, suggesting a more relaxing atmosphere, resembling the quiet waters of the lagoons: once again we get a fortuitous coincidence between the palaeogeographic scenario and the musical flavour.

From 45 to 75 m depth we crossed sands and conglomerates that were deposited close to the coastline of an ancient ocean, about 1 million years ago. Hence the Ferento area was submerged, with some coastal islands from that period visible as present-day hills. The track 'Onde' was inspired by this environment, characterized by high energy and waves.

The last composition 'Abissi' reflects the sound feature of the grey-blue clays, deposited in the deep sea during the Pliocene. During this period the area was characterised by cold temperatures, as testified to by the presence of *Arctica Islandica* fossils (a type of cold water clam). Our musical trip stops here, only because there was no more data. If we had more late-time TEM data (e.g. by using a larger transmitter loop and/or lower base-frequencies), we could have

Figure 4. *Roman era spa, taking advantage of local hot springs that deposited the travertines, directly overlying older volcanics.*

Figure 5. *The concert venue – built out of the local travertines.*

Figure 6. *Elephas Antiquus fossils found in the area, showing that African animals once inhabited this part of Italy.*

explored deeper and had more geology to interpret musically.

The musicians involved with this project were Stefano Pontani (electric guitar, loops and electronics) and Marco Guidolotti (saxophones). You can hear an excerpt of the full program here: https://www.youtube.com/watch?v=IaQLhoEQi84&feature=youtu.be, while the whole concert is available via a number of major on-line music sources like Apple's Itunes and Spotify; search for 'Live at Ferento'. If you are going to attend the next EGU (the European Geosciences Union) Assembly in Vienna in April 2018, don't miss our EM concert, called 'Sounds from the Geology of Italy', during which we'll play EMusic from four wonderful Italian sites (Venice Lagoon, Selinunte Temple, Phlegrean Fields and Castelluccio Plain). For more info about EMusic: www.emusic.world.

Antonio Menghini took a Master's degree in geological sciences at University of Rome 'La Sapienza', in 1989. He has worked as freelance geologist and geophysicist for many years. He is currently working in Aarhus Geophysics, a company specialising in the processing of Airborne EM data for mining, groundwater and geotechnical applications. He is Associate Editor of the *Journal of Environmental and Engineering Geophysics* (EEGS official review) and author of several international publications. He was Professor of Applied Geophysics at the University 'Gabriele D'Annunzio' of Chieti (Italy), during the 2008–2009 academic year. He is the inventor of EMusic and scientific director of the EMusic project.