

Andrija Mohorovičić – an extraordinary scientist who pointed his binoculars down

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An article for Naifuru - Seismological Society of Japan

Imagine strolling down Tkalčićeva Ulica – among the most romantic of numerous streets that crisscross downtown Zagreb, the capital city of modern Croatia. The everlasting energy and glamour of the passing teenagers reside here side by side with one of the highest unemployment rates in Europe, perhaps as the last standing symbols of Croatian *joie de vivre*. You pass by the statue of Marija Jurić Zagorka, a 19th century Croatian journalist and novelist known for her romantic historical novels. In one of her novels set in the 18th century old town Zagreb, a beautiful and open-minded young aristocrat Nera Keglević gets accused of witchcraft. But, through a never-ending intrigue and mystery that take place in secret passages of old town Zagreb, at stunningly beautiful medieval castles, and at the Court of House of Habsburg in Vienna, the Empress Maria Theresa, persuaded by her son Joseph, reverses the process against Nera.

After stopping by one of the numerous cafes, you approach an average adolescent with a simple question: “Who do you think was the most famous Croatian scientist of all times?” A likely answer that you receive straight away is “Nikola Tesla” but some would surprise you with an offer of “Rudjer Bošković”. Indeed, Bošković’s work in astronomy and geodesy of the 18th century was well noted, giving him a prestige of the Fellowship of Royal Society. And a lot could be sad about Tesla, to whom the world owes the debt of gratitude for his ingenious inventions and patents. Yet, this article is dedicated to the memory of Andrija Mohorovičić, a truly outstanding scientist and scholar, who put a tiny Croatia on the scientific map of the world.

Born on January 23, 1857 on the northern coast of the Adriatic Sea in the small fishing town Volosko, young Mohorovičić was growing up surrounded and fascinated by the sea. An oily surface of the sea, which in its calmness and generosity provided full fishing nets, frustrated people in its ferocity at times when the gusty Bura wind pushed masses of cold air from the Pannonian basin, often reaching the speed of 200 km/h. From his family house built of white limestone blocks that still stands just several meters away from the sea, young Mohorovičić was observing seagulls, clouds, winds and weather patterns when he started thinking about his life call. After he attended a high school in nearby Rijeka, he parted with his family, and, like many young Croatians at that time, embarked on a new life as a student at one of the prominent Austrian universities. He went to Prague, where he studied physics and mathematics, and explored his roots socializing with his Slavic peers. Taught physics courses by Mach, mathematics courses by Durege, and exposed to the theory of elasticity during his Year 3, a twenty-year old Mohorovičić was now well set to make one of the greatest geophysical discoveries of the 20th century. But, not for another period of 32 years or so, the time during which he established himself as a meteorologist.

When he returned to Croatia, he taught in high schools in Zagreb (1879-1880) and Osijek (1880-1882), then mathematics, physics and meteorology at the Nautical School in Bakar (1882-1891). During that time he married Silvija Vernić and had four sons: Andrija, Ivan, Stjepan and Franjo. Interestingly, it was the family tradition that the first son be named after the father's first name. It was also during that time that he started his meteorological research, which culminated with a PhD degree in 1893 on the basis of his thesis entitled: "*On the observation of clouds, and on the diurnal and annual change of clouds in Bakar*". He helped establish the Meteorological Institute in 1891 (later called Institute for Meteorology and Geodynamics, and today known as Geophysical Institute), where he worked until 1922, the year of his retirement. He took a lecturing position at the University of Zagreb in 1894 and became a full member of the Academy of Sciences and Arts in 1898. His work on vertical rotors in the atmosphere was widely known. For example, it was cited in Alfred Wegener's book "Thermodynamics of the atmosphere" (Wegener is known for his hypothesis of "Continental drift"). Not only he was the Head of the Meteorological Observatory in Zagreb from 1892 to 1922, but he also unified the Croatian meteorological service and took the responsibility of publishing weather forecasts on daily basis for about 20 years. It is worth noting what Mohorovičić wrote about the future of meteorology in 1901:

"The ultimate goal of the meteorologist is to formulate differential equations describing motion of the air, and to obtain, as their integral, the general circulation of the atmosphere and as particular integrals the cyclones, anticyclones, tornadoes and thunderstorms." It could be said that this thought still describes the state of the weather forecasting today.

It is not well understood what prompted Andrija Mohorovičić to turn his attention in his mid life years from meteorology to seismology. He was a true scholar; for example, apart from his mother tongue, Croatian, he spoke five other European languages and was well acquainted with Latin and Greek. He was always interested in observations, and, therefore, a good guess would be that the trigger was the fact that his homeland country was exposed to a high rate of seismicity, and seismology was at its birth stage as a new discipline in geophysics, which presented itself as a challenge. The following is how Mohorovičić described the role of seismology:

"The goal of seismology is to study the interior of the Earth, and to continue where the geologist stops; it has in modern seismographs a sort of binoculars that enables us to look into the largest of depths."

In 1901, Mohorovičić helped obtain the first electrical seismoscope (Agamennone), and, in 1905, he acquired a Vicentiny-type seismograph on loan from Budapest. This instrument became operational on 4 April 1906, which is accepted as the day of the founding of the Zagreb seismological station (ZAG), and recorded the Great 1906 San Francisco Earthquake and Fire on seismogram number 9!

On the morning of 8 October, 1909, an earthquake shook peasant houses and stables in Kupa Valley. Equipped with Wiechert seismographs and recordings in Zagreb, just 30 km to the north from the epicenter, Mohorovičić obtained additional seismograms from more than 35 other European stations. It is interesting to note that while this earthquake definitely opened a way to the discovery of the crust-mantle boundary, Mohorovičić used it to adjust his set of empirical travel time curves, which he had compiled from a number of Mediterranean earthquakes that occurred in previous

years. In an unusually long and narrative paper that appeared bilingually (in Croatian and German) in the Observatory bulletin in 1910, Mohorovičić used differential calculus and ray theory to solve for the depth to the discontinuity. Interestingly, his approach can be described as a combination of geophysical forward and inverse methods and it is interesting in the timing context of the discovery. But the critical strand that underlines rigorous mathematical approach and the subsequent discovery is the observation of two distinct arrivals of P and S waves on the seismograms in a specific epicentral distance range. The depth of 54 km that he obtained as the depth that separates the Earth's crust and mantle agrees well with the modern estimates for the area northeast of Croatia, onto which his study was constrained due to the majority of the ray paths.

Mohorovičić passed away in 1936, symbolically, in the same year that introduced another, truly gigantic discovery, by Lehmann, to the world - that the Earth has an inner core. It is on the shoulders of these exemplars where we stand today, in too big shoes to fill. But the new knowledge about the Earth is inevitably on the horizon. Chikyu's mission to drill into the Earth's mantle is a symbol of all our scientific struggles and victories, a true legacy of an outstanding scientist who once pointed his binoculars from the clouds down towards the Earth's largest depths.

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