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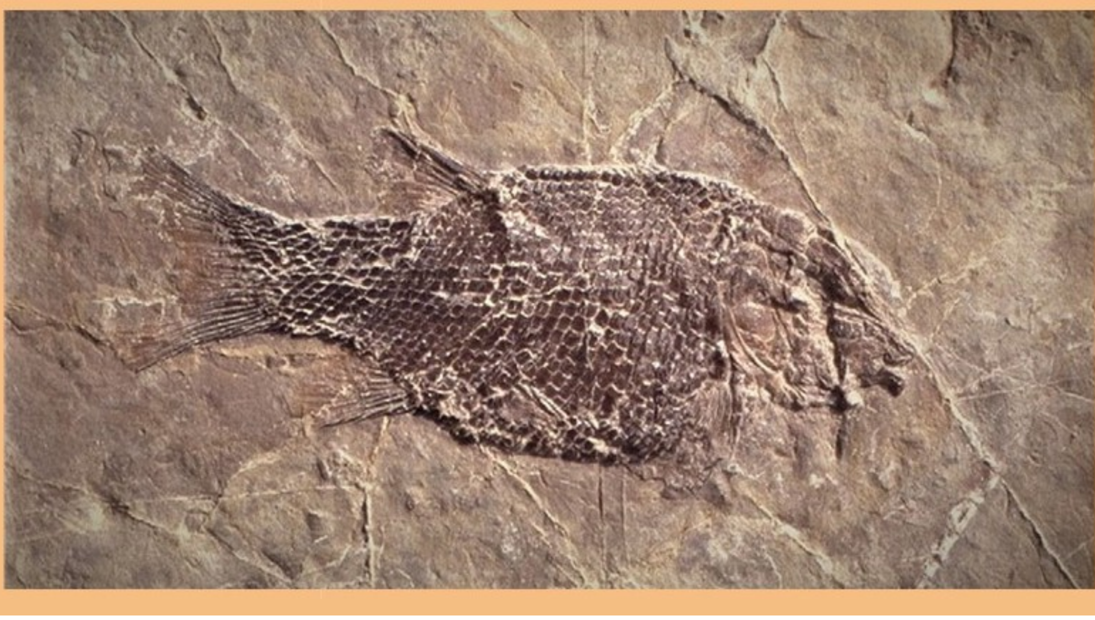

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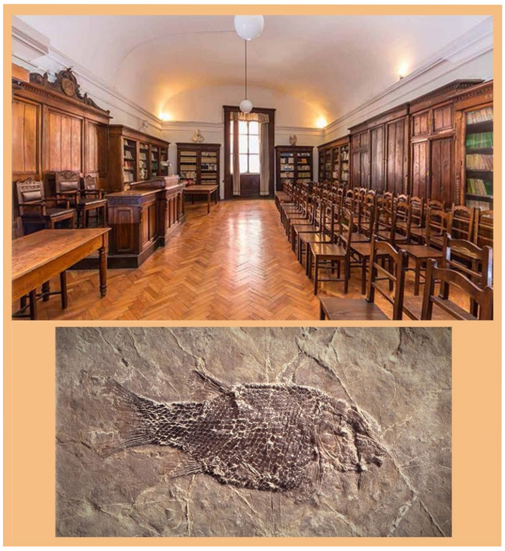

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Annibale de Gasparis, the sublime calculator of Parthenope's sky

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Abstract

Annibale de Gasparis was a mathematician and astronomer, director of the Capodimonte Observatory, and senator of the Kingdom of Italy, especially famous for the discoveries of 9 asteroids, the greatest number of discoveries made in Italy throughout the 19th century. His correspondence is scattered in some Italian and European archives and consists of more than 500 letters exchanged with over 120 correspondents, like Herschel, Le Verrier, Arago, Secchi, and Sella. De Gasparis played a relevant role in the mathematical developments of celestial mechanics, as witnessed by Hermite's letter. Furthermore, his scientific reputation went beyond the boundaries of astronomy, becoming famous in popular magazines and the protagonist of verses and books, popularizing the scientific value of his discoveries. Reconstructing the atmosphere of those years, the letters give a clear view of de Gasparis' relationships and scientific interests and present a cross-section of the human kindness of the astronomer.

Keywords: Italian Astronomer, Asteroids, Historical Archives

Riassunto

Annibale de Gasparis è stato matematico e astronomo, direttore dell'Osservatorio di Capodimonte e senatore del Regno d'Italia, famoso soprattutto per la scoperta di 9 asteroidi, il maggior numero di scoperte effettuate in Italia nel corso del XIX secolo.

Sparsi in molti archivi italiani ed europei, la sua corrispondenza è di oltre 500 lettere scambiate con oltre 120 corrispondenti, come Herschel, Le Verrier, Arago, Secchi e Sella. de Gasparis ebbe un ruolo rilevante negli sviluppi matematici della meccanica celeste, come testimoniato dalla lettera di Hermite. Inoltre, la sua reputazione scientifica ha travalicato i confini dell'astronomia, divenendo celebre sui giornali e sulle riviste dell'epoca che resero popolare il valore scientifico delle sue scoperte. Ricostruendo l'atmosfera di quegli anni, queste lettere danno una visione chiara delle relazioni e degli interessi scientifici di de Gasparis e presentano uno spaccato della bonarietà umana dell'astronomo.

Parole chiave: Astronomo italiano, Asteroidi, Archivi storici

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Introduction

The life of Annibale de Gasparis seems linked to the history of the Capodimonte Observatory in a flow of events that saw the flourishing of one of the most distinguished astronomers, both in Italy and abroad, and marked the development of the largest temple dedicated to Urania.

Due to the initiative of Charles of Bourbon (1716-1788), king of Naples, and Celestino Galiani (1681-1753), *Cappellano Maggiore*[1] and prefect of the University, a chair of Astronomy and Nautical science was established in 1735. In the following years, professors of astronomy, like Pietro di Martino (1707-1746) and Felice Sabatelli (1710-1786), and ministers, like Gaetano Maria Brancone (1670ca.-1758) and Bernardo Tanucci (1698-1783), proposed to create an observatory, like that established in Bologna and Pisa. But it was only in 1812 that Joachim Murat, king of Naples from 1808 to 1815, gave it a magnificent building in Capodimonte, worthy of his Muse. Seven years later, on the night of 17 December 1819, the astronomer Carlo Brioschi (1782-1833) made the first scientific observation from the eastern dome of the new observatory. A month earlier, on 9 November, Annibale de Gasparis was born in Bugnara, a small town in the Principality of Abruzzo in the gorges of the Sagittario river (Fig. 1). This town was also the birthplace of the pharmacist Beniamino Toro (*1794), who created the recipe for the *Amaro Centerbe* in 1817, perhaps on the occasion of his wedding, and the painter Francesco Paolo Michetti (1851 -1929), an exponent of Italian realism.

[1] He was a priest who depended on the sovereign, exercising an extensive jurisdiction, including civil, criminal, and mixed, over all the ecclesiastics assigned to the royal service over the royal chapels. Furthermore, he provided for all the religious ceremonies in the Palatine Chapel and the spiritual care of the king and the royal family. Since the Aragonese period, *Major Cappellanus* had the superintendence (*Prefectus Studiorum*) of the university with the power to appoint the rector and the readers. During the French domination, the office was suppressed and then reintroduced with the Bourbon restoration, but he became a simple court official. The oldest *Cappellanus* of the Kingdom of Naples was Joannes de Mesnelis, archbishop of Palermo and proto-chaplain of Charles I of Anjou since 1269. The last one was Filippo Gallo (1806-1890), archbishop of Patras, and chaplain of Francis II of Bourbon (Guarini, 1819).

Figure 1: Photograph of Annibale de Gasparis taken in Naples in September 1867 (Historical Archive of the Astronomical Observatory of Capodimonte).

Thirty years later, Annibale de Gasparis would have strung together a series of discoveries from the top of the Capodimonte hill. So much so the director of the ducal observatory in Modena, the astronomer Giuseppe Bianchi (1791-1866), wrote that the sky of Naples "would almost be called the favorite garden of asteroids by his work"[2] (Bianchi 1851, p.310)

A careful surveyor of the sky

De Gasparis completed his classical studies at the seminary of Chieti, and in 1838 he arrived in Naples to attend the "School of Bridges and Roads[3]".

The Kingdom of the Two Sicilies and its capital experienced a period of great institutional stability, after the brief republican period of 1799 and the French domination between 1806 and 1815, which greatly benefited the social and cultural renewal of the Kingdom. The turbulence of 1821 was far away, and the events of 1848 were beyond any possible horizon. Naples was also crossed by great scientific enthusiasm, because of the presence of prestigious institutions, like the Botanical Garden, the Astronomical Observatory, the Mineralogical Museum, and from 1841 the Meteorological Observatory on Vesuvius, as well as the University and numerous academies. Industrial transformations have also marked fundamental stages, above all the first Italian railway: Naples-Portici, a double track of 7,25 kilometers inaugurated on 3 October 1839. The cholera pandemic that had attacked Italy in 1835 had lost its vigor. So commercial exchanges, interrupted by the various health lines, gave new life to a fragile economy that had not yet grasped the transformations, which were already

[2] After the discovery of Ceres by Giuseppe Piazzi (1746-1826) in 1801, the nine asteroids of Annibale de Gasparis represent the main Italian contribution to the discovery of new planets throughout the nineteenth century. To the list are added the discoveries of Esperia, made by Schiaparelli on 29 April 1861, Josephina and Unitas made by Elia Millosevich (1848-1919) on 12 February and 1 March 1891, respectively the 303rd and 306th of the list of "Minor brothers of the Earth".

[3] The School of Application of the Corps of Engineers of Bridges and Roads was established in 1811 on the model of the École Polytechnique in Paris. Subjects taught included descriptive geometry and geodesy, rational mechanics, physics, and chemistry. Access to the school, divided into two biennia, took place through the competition of young people of any age from the Kingdom of the Two Sicilies. The school had several chairs of applied sciences, which are essential for pupils to become talented engineers or architects. Preliminary studies of mathematical sciences, calculus, including the infinitesimal one, as well as the Italian and French language and literature, were mandatory. A comprehensive proof of these subjects was required at the entrance examination. Until 1836, 145 students were admitted to the school (see: G. Ceva Grimaldi, 1839, pp.1-3).

underway in other European countries and partly in the northern states of Italy (Capaccioli, 2012, pp. 1-3).

At the "School of Bridges and Roads" de Gasparis attended courses in geometry and differential analysis held by Francesco Paolo Tucci (1790-1875) and Salvatore de Angelis (1789-1850). The two mathematicians were the promoters of an analytic-Lagrangian school that was opposed to the synthetic school founded by Nicola Fergola (1753-1824), which favored the use of the classical geometry of Euclid and Apollonius for the resolution of mathematical problems. The Neapolitan school vision of "traditionalists", continued by Felice Giannattasio (1759-1849) and Vincenzo Flauti (1782-1863), was opposed by the Lagrangian-type approach of the "innovators" who believed they could tackle mathematical questions with analytical methods. The algebraic formulas could have replaced the classical geometric figures, providing more effective solutions (Petrocelli 2020). In this methodological dialectic, Fergola's students dedicated themselves to studying new synthetic solutions to well-known geometric problems, lashing out strongly against those who fed on the geometry of Euler, Lagrange, and Monge (Nobile, 1843, pp.138-139).

Returning in 1838 from his stay in Paris, which lasted about two years, Ernesto Capocci (1798-1864), director of the Observatory of Naples[4], was looking for capable young people to instruct in the study of the sky to increase the research activities of the Observatory. This is how the young de Gasparis, Remigio Del Grosso (1813-1876)[5], Michele Rinonapoli (1818-1907)[6], and Christian Heinrich Friedrich Peters (1813-1890)[7] arrived in Capodimonte (Capaccioli, 2009, pp. 140-142).

At that time, the scientific staff of the Observatory consisted of the Director, a second Astronomer, Antonio Nobile (1794-1863), and an assistant, Leopoldo del Re (1804-1872). The latter, appointed to this position in 1833, had left the fellowship role

[4] Since its establishment, the Neapolitan observatory used the title of both the Royal Observatory of Naples and the Royal Astronomical Observatory of Naples. On the letterhead in 1888, commissioned by de Gasparis, the title of Astronomical Observatory of Capodimonte - Naples is used for the first time (see de Gasparis, 1888).

[5] Del Grosso, a father of the Pious Schools, was in the Capodimonte Observatory from 1841, working with de Gasparis, of whom he was a close friend. Two years later, Del Grosso moved to Florence at the Ximenian observatory to collaborate with Giovanni Inghirami until 1845. Back in Naples, he taught in some high schools and, in 1860, was appointed professor of applied mechanics and then of celestial mechanics at the University of Naples (see GARGANO, 2015a).

[6] Arriving in Capodimonte in 1839, Rinonapoli was mainly involved in observations of eclipses, determination of longitudes, and calculations of comet orbits. In 1845 he was appointed adjunct astronomer to the Royal Navy Observatory of Naples, where he was also interested in meteorological observations (see GARGANO, 2015b).

[7] After a short time spent at the Copenhagen Observatory, Peters moved to Göttingen, where he worked with Carl Gauss and the geologist Wolfgang Sartorius, Baron of Waltershausen. In 1838 the baron and Peters went to Sicily for a scientific campaign on Etna, carrying out an intense campaign of topographical surveys. During his stay in Sicily, Peters was commissioned to make the sundial in the Church of San Nicola all'Arena in Catania and the Cathedral of Acireale. From 1840 to 1848, he was at the Capodimonte Observatory, where he realized an accurate series of observations of the sunspots, observed comets like C/1843 D1, the great comet of March 1843, and discovered the comet 80P/1846 M1 on 26 June 1846 (see Kronk, 2003, pp. 129-168). Of liberal ideas, Peters participated with Capocci in the uprisings of 1848, so he was forced to flee to France and then to Constantinople in Turkey, where he was a scientific consultant to Reshid Pasha, Grand Vizier of Sultan Abdul-Mejid II. In 1854 he sailed to America, and in 1859 he was appointed director of the observatory at Clinton's Hamilton College. He continued his studies on the comets and the Sun and discovered 48 asteroids and some galaxies and nebulae (see Gargano, 2015c) .

(*Alunno*) vacant, lacking a young student capable of carrying out scientific tasks and activities with rigor and reliability. In December 1839, Capocci proposed to the Ministry of the Interior to give that position to de Gasparis: "Among the students who attended the Observatory to apply the theoretical knowledge of science to practical uses, the younger Mr. Annibale de Gasparis has now finally presented. For over a year, he has given the most certain proofs for his zeal and ability so that the Observatory now relies on his work with confidence for magnetic, and astronomical observations, etc" (Capocci, 1839). In June 1840, the king of Two Sicilies, Ferdinand II, approved the request. In Capodimonte, de Gasparis began to learn how to extricate himself with scientific instrumentation and devoted himself to studying mathematics and celestial mechanics. He also established a relationship of great esteem and friendship with Capocci and his family[8], animated by the same political sentiments and the same cultural interests.

His first scientific activities are testified by the communications made by Capocci and Nobile at the Sciences Academy of Naples and by de Gasparis himself at the Accademia degli Aspiranti Naturalisti[9] of which he was supernumerary member from 29 May 1842, and then ordinary from 9 July 1846. He participated in the thermometric, hygrometric, pluviometric, and magnetic observations, together with the astronomers and the technician of the Observatory, Giovanni Cortese (1789-1857). He compiled the quarterly summary reports of the meteorological measurements made by some members of the Academy of Aspiring Naturalists in various private places in the city, comparing them with those obtained in the observatory. Published in 1843 an essay in which he compared the rainfall measured in the Capodimonte Astronomical Observatory and the Navy Observatory, located in the historic center of the city, de Gasparis proposed an interesting project to realize an extensive stations network for meteorological observations throughout the Kingdom (de Gasparis, 1843). Meteorological observations were no longer considered easy activities to be entrusted above all to pupils, as Capocci wrote, but "Meteorology requires at the same time the complex calculations of the astronomer, the most profound research, and the careful experiences of the physicist. Now elevated to the very noble rank, embracing all the general physics of the globe, this science, by itself, would require the care of an entire observatory" (Capocci 1840, p.78). In this

[8] From his marriage with Maria Almerinta Giacinta Farina (*1799) Capocci had 7 children: Stenore Filippo (1823-1886), Federico Oscarre (1825-1904), Teugro Beniamino (1827-1878), Dermino Carlo (1830-1914), Euriso Giacinto (1832-1910), Ulrico Gaetano (1835-1852) and Fiorina Almerinta Giacinta known as Romilda Dalmivena Nidia Carolina (*1839). It was a family with profound liberal ideas and involved in the turbulent events of the Risorgimento, starting with the riots of 1848, when, on the morning of 27 January, Oscar Capocci, pulling out the tricolor cockade, exclaimed with the other demonstrators: "long live the Constitution, long live Freedom!" Two days later, the Capocci brothers left Naples for Lombardy-Veneto. To learn more about the biography of the astronomer born in Picinisco, in Terra di Lavoro province (see del Pezzo, 2015).

[9] It was founded in 1838 by Oronzo Gabriele Costa (1787-1867), a professor of zoology, aiming to increase the level of scientific knowledge of students. The Academy was a sort of elite school based on the principles of collaboration and friendship. The members were obliged, under penalty of exclusion, to research in a wide field of naturalistic investigation from geology to meteorology, from botany to physics, and to medicine. The Academy was closed after 1848 due to the participation of many of its members in the Springtime of the peoples. It gave new life in 1861 (see Borrelli, 2003, pp. 95.127) .

way the director of Capodimonte highlights both de Gasparis' trusted skills and the establishment of the new meteorological observatory of Naples on Vesuvius entrusted to the direction of Macedonio Meloni (1798-1854).

In the field of astronomical research, by introducing observations and scientific notes on comet C/1840 U1, discovered by Carl Bremiker (1804-1877) in Berlin, Capocci presented to the members of the Sciences Academy of Naples the orbital parameters calculated in the best possible way "with the Laplace method by Mr. de Gasparis, a fellow of our Observatory" (Società Reale, 1841). This one appears to be the first note in the literature about an astronomical computation by de Gasparis. In 1842, de Gasparis participated in the observation of the Perseids shooting stars, counting 473 in 4 hours, as well as having seen "a large fireball to the southeast"; while a year later, Capocci involved him in observations of comet C/1843 J1, discovered by Félix-Victor Mauvais (1809-1854) in Paris on 3 May. Using these measures, the young astronomer calculated the orbital elements of the comet; and the director of the Observatory was fully satisfied with these values. Finally, in the following years, he assisted the Capodimonte astronomers in the observations and calculation of the orbital parameters of comet C/1844 N1 and the other two: 54P/1844 Q1 and C/1845 D1, discovered by the Jesuit Francesco de Vico (1805-1848) at the Roman College Observatory in Rome.

On the occasion of the vii Meeting of Italian scientists, held in Naples between 20 September and 5 October 1845, de Gasparis presented a table to solve the cubic equations, obtaining great appreciation for the relevant result. The following year he published an article describing the mathematical process to obtain "two very remarkable and suitable equations to determine the inclination of the orbit and the longitude of the node", using only the second law of Kepler. As a practical application of these new formulas, he calculated the orbit of Vesta from four observations of the planet made by Gauss, obtaining "very small errors" (de Gasparis 1846b). In two communications to the Academy of Sciences of Naples, de Gasparis presented a new shorter method to correct the approximate values of the two variables, applying it to calculate the orbit of Vesta (de Gasparis 1846b, 1847) and subsequently to that of Hebe, discovered by Karl Ludwig Hencke (1793-1866) on 1st July 1847. Explaining to the Neapolitan scholars the observations of the new asteroid made at Capodimonte, Capocci said that Hebe "was found by the pupil Mr. Annibale de Gasparis among many little stars in Ophiuchus on the evening of 4th August. Thenceforth it has been regularly observed. The same diligent young mister de Gasparis promptly applied his formulas to determine the place where the new body moves around the Sun, and the result of his calculations conformed to those of misters Faye and Goujon in Paris" (Capocci 1847b). Augustin-Louis Cauchy (1789-1857) took an interest in this work and presented "the method of mister de Gasparis" to the members of the Paris Academy of Sciences, as a simplification of Lagrange's for determining orbits. He placed the method of the young astronomer on par with the solutions given by the most famous mathematicians, such as Lambert, Olbers, and Legendre. This appreciation convinced the Neapolitan academics to ask the King for the attribution of an "honorary degree in Mathematics so that he can begin teaching it, which will greatly benefit young people who want to learn it". On 25 September, Ferdinand II of Bourbon granted him the degree in Mathematics among the eight planned for the Faculty of Sciences in that year (Rendiconto 1847, pp. 47, 256 and 423).

The gardener of the asteroids

The discovery of Uranus, made by William Herschel (1738-1822) in 1781, was among the first signs of the complexity of the Solar System. Subsequent discoveries: Ceres on New Year's night 1801 by Piazzi, Pallas in 1802 by Heinrich Wilhelm Olbers (1758-1840), Juno in 1804 by Karl Ludwig Harding (1765-1834), and Vesta in 1807, Olbers' second small planet, gave the idea that the area between Mars and Jupiter was heterogeneous and crowded by a great multitude of celestial bodies.

The scientific conjectures did not agree on the nature and formation of this large number of planets. Olbers considered them fragments that belonged to an original planet that had disintegrated due to a violent catastrophe, be it endogenous or caused by the impact of a comet. This hypothesis turned out to be so convincing that the astronomer of Padua Giovanni Santini affirmed that "there was certainly no other scientific hypothesis crowned with happier successes" (Santini 1819, p. 274). On the other hand, Capocci thought it "much more reasonable to assume that… the necessary conditions for the concentration of all the surrounding matter around a single center had not been created. Thus, a considerable number of minor centers have arisen, which remaining independent have… produced many distinct asteroids" (Capocci 1847a). If there were few certainties on these hypotheses, although the idea of the astronomer from Picinisco was not far from the reality of the nature of dwarf planets and asteroids, from 1807 and for the following forty years no astronomer managed to find others.

"When, towards the end of 1845, Mr. Hencke discovered a new asteroid, Astrea, [astronomers expected] to see others gradually recognized" (Capocci 1847a). Unlike Neptune in 1846, calculated by Urbain Le Verrier (1811-1877) through the gravitational perturbations on Uranus, Astrea and the asteroids, that followed over the years, were discovered thanks to "a new powerful means that astronomy had obtained with the famous plates of the Berlin Academy, which offered astronomers the way to recognize a planet, being in them accurately represented all the stars close to the equatorial region up to the tenth magnitude" (Capocci 1847a). The 24 "Stunden" of the Akademische Sternkarten and the related star catalogs were the results of an important scientific initiative commissioned by the Berlin Academy of Sciences (Wolfschmidt 2022). In 1824 Friedrich Wilhelm Bessel (1784-1846), director of the Prussian capital's Observatory, wrote to the leading European astronomers inviting them to collaborate in the creation of the first catalog resulting from an international collaboration. "The knowledge and the description of all the fixed stars in the sky have always and rightly been considered a subject of the greatest astronomical interest", wrote the German astronomer, "if a planet or comet is to be observed off the meridian, this aim will usually only succeed if several stars are always well-determined in its vicinity. If astronomers work really towards the discovery of all the main planets in our solar system, a complete description of the stars must precede it. Holding it, they will only have to observe a region of the sky through a telescope to immediately decide whether there is something new there" (Bessel 1859). Published between 1830 and 1858, the Berlin plates became a very effective tool for the discovery of new celestial bodies. The experimental verification of Le Verrier's mathematical intuition was also carried out by Johann Gottfried Galle (1812-1910), using the xxi hour, made by Carl Bremiker (1804-1877), of the new celestial charts of Berlin. However, as Capocci wrote in the Calendario di Napoli of 1848, "Thus, it was natural to expect the discovery of other similar asteroids, but no one would certainly have imagined seeing three more discovered in a few months!" Indeed, from July to October 1847, Hebe by Hencke, Iris and Flora by John Russell Hind (1823-1895) were discovered. Commenting on the extraordinary triple discovery, Capocci wrote that "everyone is rightly authorized to imagine an unlimited number in that area which was first considered completely deserted and then recognized as so rich in tiny celestial bodies!" The new star charts were not the only privileged tools for the discovery of new celestial bodies. To these must be added, Capocci wrote again, "the advantages of the more powerful optical instruments for understanding the sky [and] the beautiful project of Mr. Valz, with which it will be possible to proceed methodically in search of all these small bodies" (Capocci 1848).

Benjamin Valz (1787-1867) was the director of the Marseille observatory and a skilled comet calculator. In 1847, he proposed to the Paris Academy of Sciences an observational project to discover all the small planets in just four years with the collaboration of twelve astronomers, each would have to deal with a particular area of the sky using an ecliptic atlas showing all stars up to 11th magnitude within 3° of the ecliptic. According to Valz, these new celestial maps were necessary due to the declination limits of the Berlin maps, which did not cover a large part of the ecliptic area where the probability of discovering new planets would have been greater. Furthermore, Valz underlined the important consideration that the conclusion of the Berlin publication would have taken a few years. The ambitious goal that the Marseille astronomer set himself was "not to find one more planet [but] to find all of them" (Valz 1847). Le Verrier supported this proposal, and in 1852 Jean Chacornac (1823-1873), a young astronomer, was hired to help Valz in this endeavor. The same enthusiasm animated the private observatory of George Bishop (1785-1861), a wealthy London patron who, in November 1846, promoted the product of an ecliptic atlas that would have allowed John Russell Hind to discover ten new planets (Descamps 2015).

Capocci and the Capodimonte astronomers understood the value of Valz's idea for the discovery of new asteroids, "so that within the space of only four years we can expect to see a much greater number discovered" (Capocci 1848). This was the scientific purpose that Capocci and de Gasparis intended to pursue right from the beginning of 1847. The Alunno of Capodimonte began "to mark all the stars up to 14th magnitude included and visible in a non-illuminated field on an area having the ecliptic as its axis and about two degrees wide, taking advantage of the wise advice of Mr. Capocci" (de Gasparis 1849b). In a communication to the Naples Academy of Sciences of 1849, de Gasparis stated that "a portion of this long work is already complete, and I flatter myself that my eyes and enthusiasm will assist me in completing it… I have often used the plates of Berlin to add the stars, which are slipped out an initial search due to their smallness" (de Gasparis 1849b). In the correspondence with the Dutch astronomer Frederik Kaiser (1808-1872) and the German scientist Alexander von Humboldt (1769-1859), held between 1850 and 1852, de Gasparis described in great detail the method of his observations: about 130 nights a year spent comparing star maps in an area of about 30 square degrees straddling the ecliptic. Thanks to this observational technique, de Gasparis was able to discover new asteroids, "rediscover" those already known, and study some variable stars. "In my research, I had the intuition not to get too close to the ecliptic… I directed my observations to that part of the sky not too far from the opposition point with the Sun… I almost always used the plates of Berlin, adding all the missing stars up to the 11th magnitude" (de Gasparis 1850c). Furthermore, de Gasparis was convinced that the outermost zones of the Solar System were rich in planets, and said he wanted to work hard and incessantly in the hope of finding a new planet beyond Neptune, a thought which he defined as an obsession (de Gasparis 1853).

Having defined the observation technique, he had to choose which telescope to use. Actually, de Gasparis did not have many options. The instrumental equipment of the Observatory counted on only two equatorial telescopes: the so-called Fraunhofer telescope with a 17.5 cm lens and a focal length of 302 cm and Reichenbach's one with an objective of just 8.3 cm and a focal length of 120 cm. These were the instruments purchased by Federigo Zuccari (1783-1817) at the time of the foundation of the new Capodimonte observatory in 1812, which arrived in Naples in February 1815 (Gargano 2015, pp. 75-76)). However, only the smaller telescope was housed in a dome, the northern one, while the Fraunhofer telescope, too large to fit in one of the domes, was placed in the hall of columns and used on the forecourt of the Observatory[10]. Trusting in the technical potential of Reichenbach's equatorial telescope (Fig.2), which was far from cutting-edge in the mid-nineteenth century, de Gasparis discovered nine asteroids between 1849 and 1865. Just one less than those discovered by Hind who, however, in the Bishop's observatory in Regent's Park in London, had at his disposal a Dollond

[10] Observing the sunspots with this telescope on 11 May 1845, de Gasparis, Peters and Capocci noticed a meteor shower passing over the solar disk. "A round body with the size of Mercury… passes through the luminous image of the Sun with a linear motion and a specific speed and then disappears… They all had a well-defined circular shape, very black in the center". The unusual phenomenon was also observed by the Irish astronomers Edward Joshua Cooper (1798-1863) and Andrew Graham (1815-1908) with a Cauchoix telescope installed in their Neapolitan residence at Villa Ruffo. It first impressed astronomers and then prompted them to follow and record it carefully. Comparing the different observations, the Capodimonte astronomers concluded that the "large number of small globes" were nothing more than a heavy meteor shower (see Capocci, 1845, pp. 161-165).

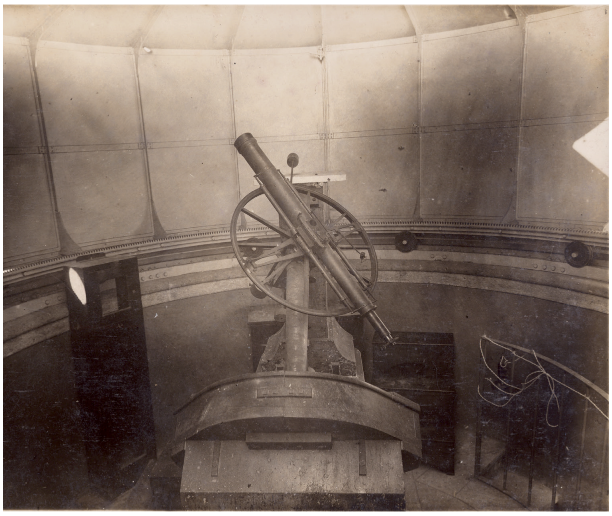


Figure 2: Reichenbach's equatorial telescope in the northern dome of the Observatory, c.1929. (Historical Archive of the Astronomical Observatory of Capodimonte).

equatorial telescope, built in 1836 with an objective of 17.8 cm and a focal length of 327 cm[11]. The discovery of the asteroid Irene joined the two astronomers even more. Hind first observed it on 19 May 1851, four days later, the new small body was found in the sky by the astronomer of Capodimonte (De Ritis 1852, pp. XVIII-XIX). This scientific competition inspired Salvatore Proja (1800-1871), lincean and professor of physics at the University of Rome, to write: "Historians say that the Athenians raised a statue to Anaxagoras for teaching that the heavens were crystal, and the moon a semi-glowing body: *risum teneatis Amici*!... What they would have done for Hind and De Gasperis, I don't know" (Proja 1853).

The nine planetary discoveries

The series of Neapolitan discoveries began on the evening of 12 April 1849 when de Gasparis, following his work scheme, was intent on recording the stars up to the 14th magnitude not present in the xii hour of the Berlin star atlas. A new bright object appeared to him. He continued to observe it in the following nights, and he was able to confirm on 24 April that it was "a new planet", his first asteroid[12]. Out of consideration for his director, "having acted as father and teacher, and bestowed advice and help of all sorts", he offered Capocci the honor of naming the asteroid. Capocci has chosen Hygiea to celebrate the goddess of health, daughter of Asclepius and Epione (de Gasparis 1849a). However, the name of the asteroid was not mentioned in the first communications to the European scientific community. Chosen by Capocci, it was communicated to the King of Naples on 8 May for approval. The English astronomer John Herschel (1792-1871), son of William and known for his extensive catalog of multiple stars, reading the letter from his Neapolitan colleagues on the new discovery, suggested calling the new planet Parthenope, after the mythical founding siren of Naples. In a letter to the English mathematician Augustus De Morgan (1806-1871), he wrote that "no name has yet been mentioned. What do you think of Parthenope (being a Neapolitan)? I should think it will occur as a matter of course for Gasparis if he has any classical

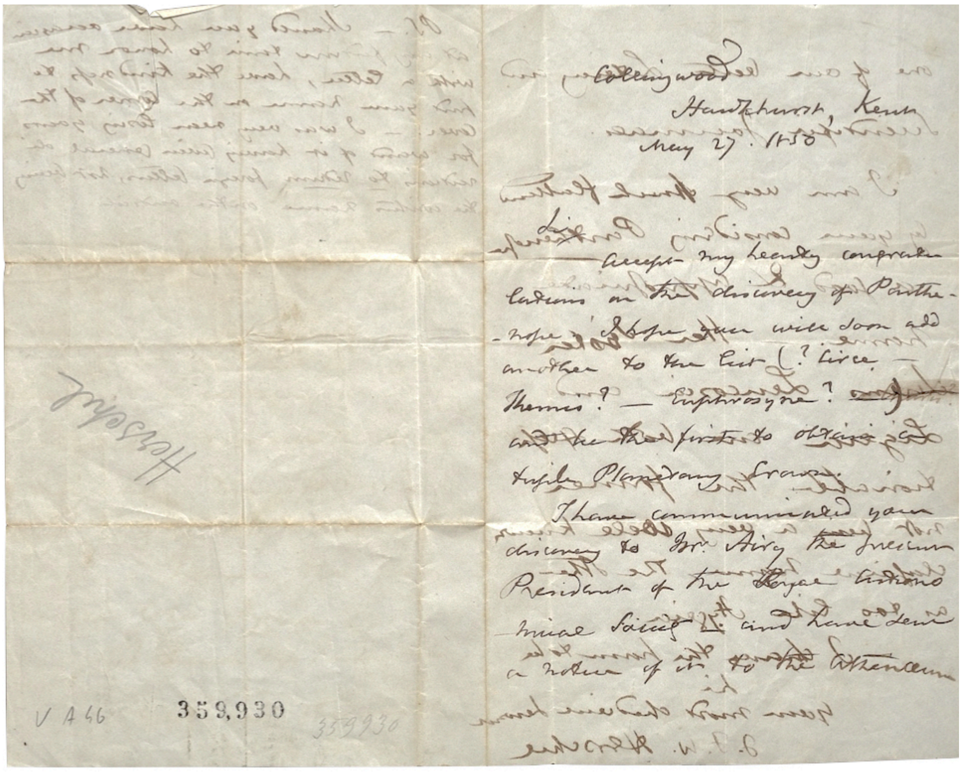
[11] Upon the death of George Bishop, his son George junior first transferred the entire instrumental collection to the new observatory at Meadowbank on the Thames shore, where the observing conditions were better, and then, in 1878, he donated Dollond's telescope to the Naples Observatory, directed by de Gasparis, together with Barraud's pendulum clock, Troughton-Simms altazimuth telescope and a valuable book collection.

[12] The term asteroid was introduced by William Herschel in 1802, after the discoveries of Ceres and Pallas (see Herschel, 1802, pp. 213-232). However, it was long overlooked by calling this class of objects planets or small planets. Herschel's proposal also caused Piazzi to burst out, who believed that the English astronomer's intention was to demean his discovery (see Chinnici, 2020, pp. 22-26).

reading" (Herschel 1849). A few days later, he reiterated the wish in a letter to Scottish physicist James Forbes (1809-1868). But the choice has already been made. The idea of Herschel rebounded in Naples, and, on the evening of 12 May 1850, de Gasparis concluded all his efforts to realize a Parthenope in the sky for Mr. Herschel, as the Capodimonte astronomer wrote to Heinrich Christian Schumacher (1780-1850), director of the journal Astronomische Nachrichten. Afterward to Parthenope discovery, Giovambattista Pianciani (1784-1862), a Jesuit physicist and teacher of Angelo Secchi (1818-1878), wrote that "the discoverer wanted to write in the sky the name of his sunny and beautiful country. He made his siren leave the sea of Posilippo and Mergellina to let her inhabit the celestial space" (Cronaca contemporanea, 1851). Having verified the discovery with subsequent observations, de Gasparis wrote some letters to Italian and European astronomers to inform them. On 13 May he wrote to Schumacher and Le Verrier, to whom, emphasizing that Parthenope was a mermaid and not a divinity, he asked: "the permission of an astronomer so friendly with the sky in order to welcome her to the court of Olympus" (de Gasparis 1850b). On the same day, the Capodimonte astronomer also wrote to John Herschel, confessing "to be indebted to the desire to make him a Parthenope in the sky" (de Gasparis 1850a). He was so happy to have satisfied Herschel, that Schumacher writing to Herschel, with a touch of irony, said that de Gasparis "announces me the discovery of a new planet, of which discovery you are the cause" (Schumacher 1850). The reply of the reserved Herschel was not long in coming. On 27 May 1850, he sent a magnificent letter to de Gasparis in which, flattered by the choice of name, he expressed his "sincere congratulations on the discovery of Parthenope". Furthermore, he wished the Neapolitan astronomer to "soon add another [planet] to the list (? Circe - Themis? - Euphrosyne?) and be the first to obtain a triple planetary crown" (Herschel 1850) (Fig. 3). A wish that came true in less than six months. Indeed, on 2 November 1850, de Gasparis discovered Egeria, an asteroid dedicated to the nymph advisor of Numa Pompilius, the legendary second king of Rome[13]. On this occasion, the French astronomer Le Verrier had the privilege of naming the new asteroid. His father Angelo was the first to be informed of this discovery with a letter dated 4 November in which he recalled that during the last summer holidays, his mother Eleonora wished him "to find as many as four". Because even among scientists the mother is always the mother, There is no Herschel who overtakes!

The scientific and academic celebrity gathered by de Gasparis so quickly and in the most unexpected way, obtaining important commendations and awards, made Francesco De Sanctis (1817-1883) affirm: "I no longer believe in the philosophy, and I became an astronomer. De Gasparis guessed it: knight, professor, and a lot of money. Let's talk about the stars, and leave

[13] Ancient Romans celebrated Numa Pompilius for his wisdom and the original framework of laws and rites he implemented to strengthen the new Roman institutions. According to Plutarch and Livy, Egeria, an archaic Roman deity of springs attributed with prophetic and inspiring powers, taught Numa Pompilius to be a wise legislator. During their meeting and walks in the woods, she dictated to him the political and religious reforms, including a lunar calendar of 355 days and 12 months plus an intercalary one, *Mercedonius*, to accord it with the solar cycle (see Titus Livius, 1485, c3v-c4r).



Collingwood
Hawkhurst, Kent
May 27. 1850

Sir — Accept my hearty congratulations on the discovery of Parthenope. I hope you will soon add another to the list (? Circe, Themis? — Euphrosyne?) and be the first to obtain [illegible] triple Planetary Crown.

I have communicated your discovery to Mr. Airy the present President of the Royal Astronomical Society and have sent a notice of it to the Athenaeum

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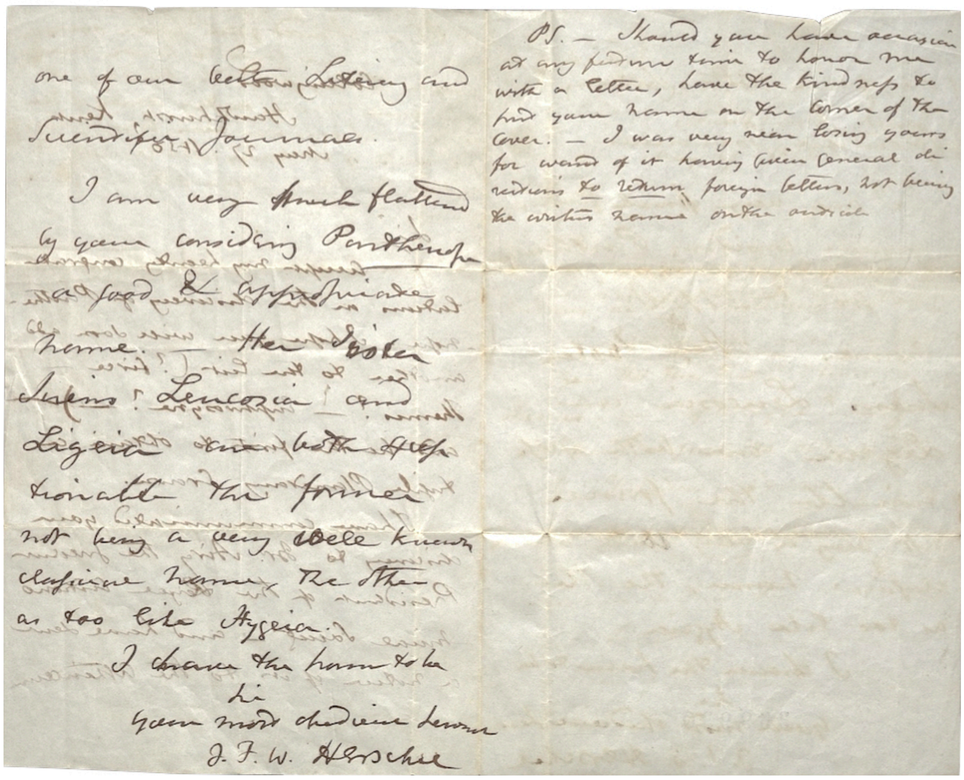
Herschel



one of our leading Literary and Scientific Journals.

I am very much flattered by your considering Parthenope a good & appropriate name. — Other good ones are Sirens! Leucosia! and Ligeia — but both these are objectionable the former not being a very well known classical name, the other as too like Hygeia.

I have the honor to be
Sir
your most obedient servant
J. F. W. Herschel

P.S. — Should you have occasion at any future time to honor me with a letter, have the kindness to put your name on the corner of the cover. — I was very near losing yours for want of it having given general directions to return foreign letters, not bearing the writer's name on the outside

Figure 3: The John Herschel's letter was recently found in the National Library of Naples together with six others signed by the main protagonists of astronomical science and culture of the mid-19th century. In addition to Herschel's letter for Parthenope's discovery, this nucleus of documents includes letters from British astronomers George Airy of the Greenwich Observatory and John Russell Hind, the French scientist François Arago and the Belgian astronomer Adolphe Quetelet. Moreover, the letters of the German scientist and explorer Alexander von Humboldt and the letter signed by Kaiser Frederick William IV of Prussia. (courtesy: National Library of Naples, Manuscripts and Rare Section).

the earth alone" (De Sanctis 1858), while the English industrialist John Ashton Nicholls (1823-1859), meeting the astronomer during his trip to Naples, noted: "I met Annibale de Gasparis, the astronomer [who] discovered three planets; he is quite young and very poor" (Nicholls 1862, p. 75).

The enthusiasm for the Neapolitan discoveries, which occurred in such a short time and made by a young astronomer little known outside the borders of the Kingdom, let to think of abstruse and elaborate observational and computational techniques. De Gasparis described his daily work as a precise investigator of the sky in a clear and easy way, but only in a meeting of the Naples Academy of Sciences. Frederik Kaiser, director of the Leiden Observatory, wanted to highlight the Neapolitan discoveries in the volume on the history of planetary studies that he was publishing, so he asked de Gasparis for details on his very recent discoveries. The astronomer of Capodimonte replied quickly with his usual courtesy, giving deep awareness to the requests of his Dutch colleague. In his volume, Kaiser expressed highly critical considerations toward Italian observers, arguing that "astronomy, which had flourished in Italy at the beginning of this century, subsequently withered away". However, he acknowledged to de Gasparis that he had undertaken an activity that seemed completely extraneous to the Naples observatory while showing disappointment with the techniques used. He wrote: "we can now judge that an endeavor like that of de Gasparis is little proportionate to the resources available at the Naples observatory and more suitable for the amusement of a student than for the notable occupation of an accomplished astronomer" (Kaiser 1851). The book, written in Dutch, was not widely circulated in Europe, and no copy seems to have ever reached Italian observatories.

About nine months after Egeria, on 29 July 1851 de Gasparis, unaware of the severe judgments of the Kaiser, discovered Eunomia, a name imposed by King Ferdinand II, inspired by one of the Hours which is the personification of legality. Egeria's discovery took place two months after Irene, the asteroid identified in the Neapolitan sky four days after the first observation made by Hind in London. Complimenting his colleague from across the Channel, de Gasparis underlined the unusual simultaneity that "enriches science with a unique event of this sort" (de Gasparis 1851). The following year he discovered Psyche (Fig. 4) and Massalia, the latter in honor of the city of Marseilles where Chacornac observed it a few days after the Neapolitan astronomer.

For the discovery of his fifth asteroid, he had sought the availability of Humboldt to give it the name, but the German polymath, complimenting the Capodimonte astronomer for the "brilliant discoveries due to [his] wisdom and in-depth topographical knowledge of the celestial vault and the stellar world far beyond the 8th magnitude", declined the invitation out of a feeling of modesty (Humboldt 1852). De Gasparis, therefore, decided to call the new asteroid Psyche. After the discovery of Themis on 5 April 1853, so named by Angelo Secchi, de Gasparis was forced to interrupt his observational activity. The cold and night humidity caused severe inflammation in his left eye, which could have irreparably compromised his vision. For the next seven years, de Gasparis returned to his original

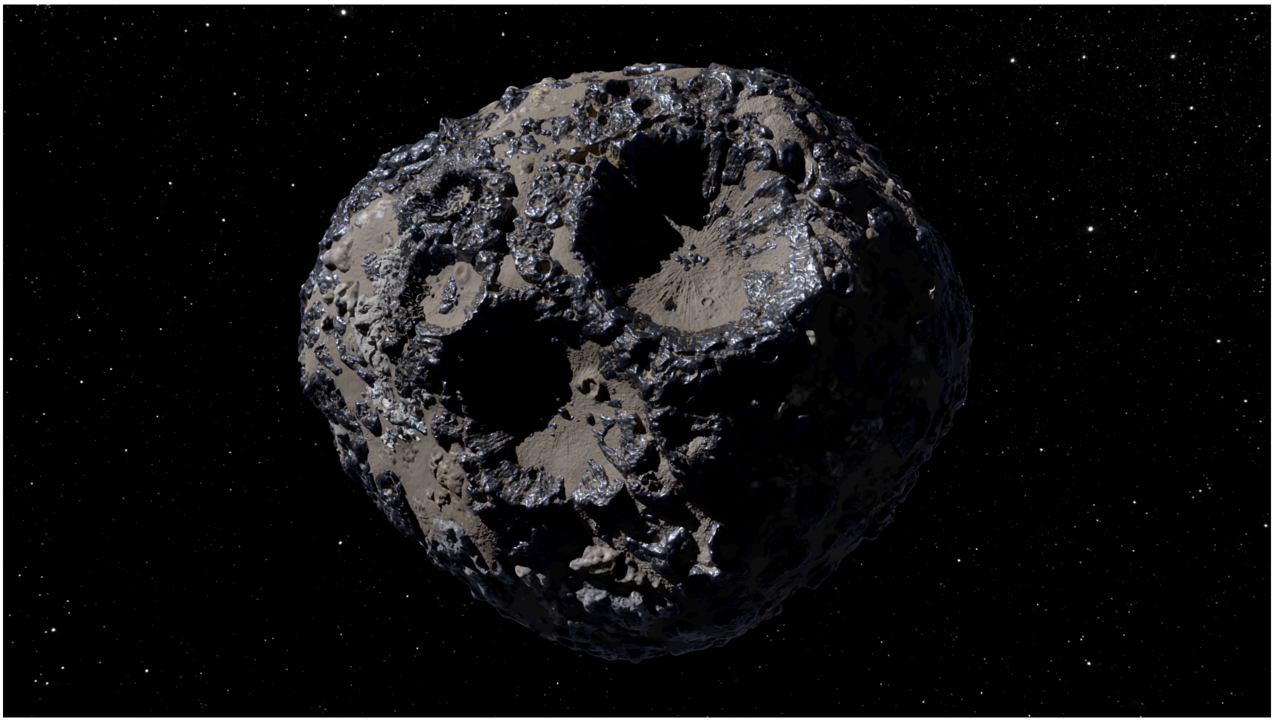


Figure 4: Rendering of the asteroid Psyche, a world not made of rock and ice, but rich in iron and nickel, continues to have a great scientific interest as scientists believe it could come from the nucleus of a planetesimal, a primordial object at the basis of the formation of the Solar System. NASA's Psyche mission, coordinated by Prof. Lindy Elkins-Tanton of Arizona State University will explore this asteroid for the first time to test the hypotheses advanced by astronomers. (courtesy: NASA/JPL-Caltech/ASU).

scientific passion: celestial mechanics, by elaborating mathematical formulations for the calculation of orbits and giving a solution to the three-body problem. He deepened his studies on the Kepler Problem looking for simple ways and sure solutions for the determination of the eccentric anomaly of comets and asteroids. In 1867 he published a work on transcendental functions, which in 1881 earned him the compliments of Charles Hermite (1822-1901) for the elegance and simplicity of calculation of the *functio inexplicabilis*, as Euler defined those functions which can be expressed neither with determined expressions nor with the roots of the equations. Even Wilhelm Klinkerfues (1827-1884), a pupil and assistant of Gauss in Göttingen, praised his studies on the solution of Kepler's equation. Commenting on the judgments of the German astronomer, de Gasparis said he was so proud of them that "he would have gladly donated five of his planets to obtain them" (Mancini 1892).

With the unification of Italy, Capocci and de Gasparis were appointed as Senators of the Kingdom. At the opening of the parliament, which took place on 17 March 1861, the Neapolitan astronomer arrived in Turin with a new planetary discovery (Gargano 2011) which he thus communicated to Terenzio Mamiani (1799- 1885), Minister of Education: "I promised prof. Capocci, director of the Neapolitan Observatory[14], to pay him

[14] For his adherence to the Springtime of the Peoples, Capocci was ousted from the direction and scientific activities of the observatory in 1850. With the arrival of Garibaldi in Naples in September 1861, one of the first acts that the General signed was the readmission to the office of Ernesto Capocci.

homage to the ninth planet, which I was able to discover. Lucky to see my wish fulfilled, I proposed various names, first among everyone that of Ausonia, which Mr. Capocci has adopted. Now the classical name of our classical country is therefore fixed in the sky" (de Gasparis 1861). Finally in 1865 his last discovery, Beatrix, the asteroid dedicated to Dante Alighieri. For this discovery, the poetess Giannina Milli (1825-1888) composed an impromptu poem: "La nuova stella Beatrice", writing these verses: [Italy] "applauded with emotion the happy idea of the philosopher who called you by the beloved name of Beatrice when he saw your pure light. The wise man from Abruzzo fixed his sharp and inquiring gaze on you and thus inscribed in the sky the most solemn homage to Dante all over the world. While every other sacred monument erected to him were to perish, you, traveler of the sky, will remain with the name he eternalized" (Milli 1866). She recited this ode during the meeting of 26 April 1866 of the Academy of sciences, letters, and arts in Modena, of which de Gasparis was an honorary member.

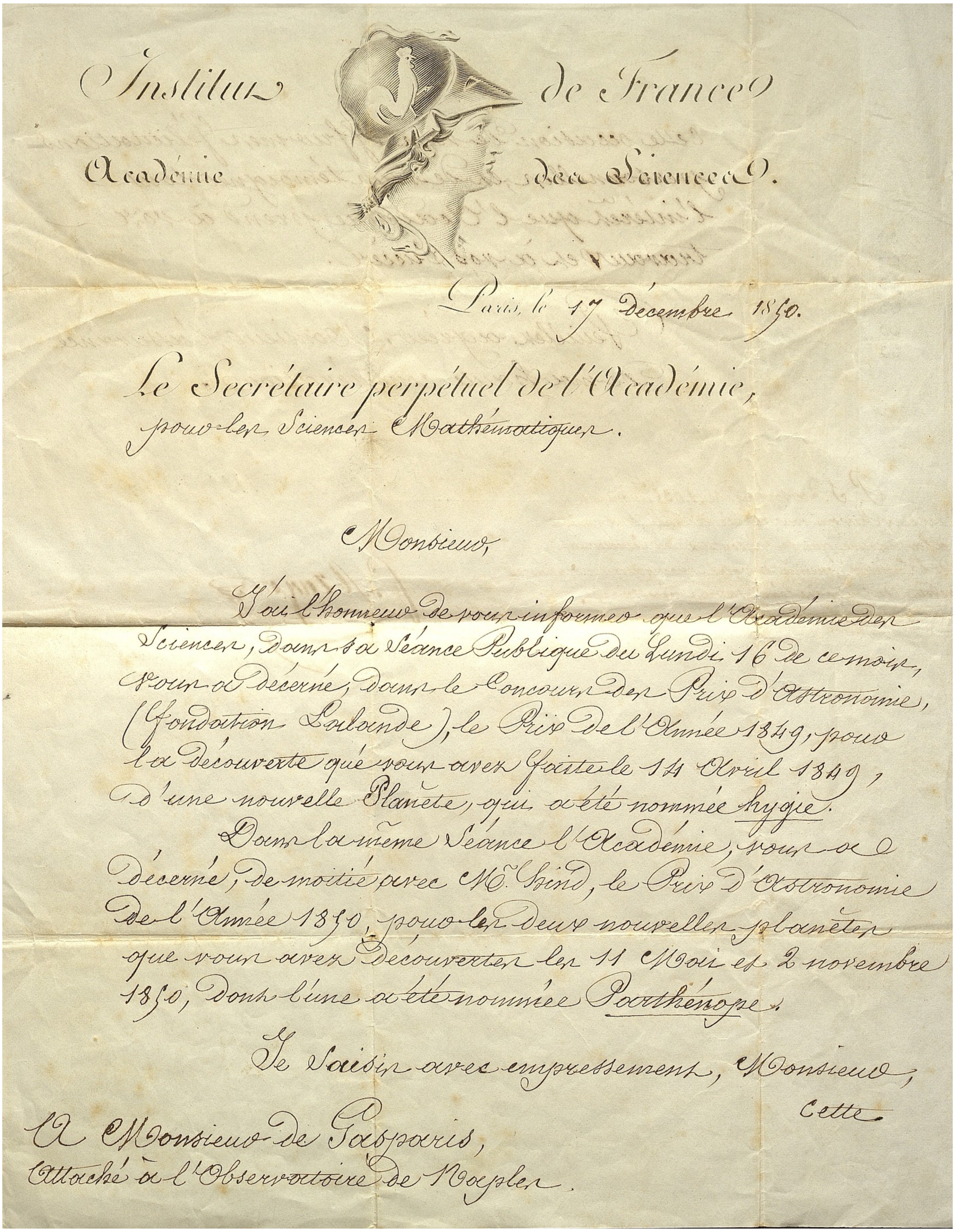
Scientific glory and popular fame

The impressive sequence of discoveries brought him a celebrity in the country and esteem among the eminent scientists of the time, François Arago (1786-1853) and Urbain Le Verrier in France, Heinrich Christian Schumacher in Germany, John Herschel and George Biddell Airy (1801 -1892) across the Channel, just to name a few.

His elegant method for calculating planetary orbits proposed in 1847 has already earned him the appreciation of Cauchy and an honorary doctorate in mathematics. His astronomical discoveries then gained him numerous national and international honors. In 1851[15] the Royal Astronomical Society awarded him the gold medal, making de Gasparis the second Italian astronomer out of five who have received it to date. Furthermore, he was the only astronomer to be awarded the *"Prix d'Astronomie"*, better known as the Lalande Prize (Fig. 5), by the Académies des Sciences of Paris for five consecutive years, from 1849 to 1853. Frederick William IV of Prussia awarded him the knighthood of the Red Eagle in 1854, while the emperor of Brazil Pedro II, in 1872, granted him the title of knight of the Imperial Order of the Rose. In his country, the University of Naples entrusted him with the chair of astronomy in 1851, and the following year the Academy of Sciences of Naples awarded him the Prize in Transcendent Astronomy, while at the Capodimonte Observatory, he continued to be an "Alunno", an ante litteram temporary position[16], until 1855 when he was appointed assistant astronomer (de Gasparis 1855). In 1861, Quintino Sella (1827-1884), general secretary of the Ministry of Public Education, announced to him the decision of Vittorio Emanuele II to create him as an officer of the Order of Saints Maurizio and

[15]He held the chair of astronomy on 29 July 1851, then became Full Professor of astronomy, geodesy, and mathematical geography on 29 October 1860, and Professor Emeritus in September 1889. Furthermore, de Gasparis also held the position of president of the Faculty of Mathematical Sciences for the years 1862-1863, 1874, and 1881-1882 (see Gatto, 2000)

[16] A complete list of the honors granted to De Gasparis and the academies of which he was a member is available on the *Polvere di Stelle* web portal at the address: https://bit.ly/3baMCl3 (last access: 2 January 2023).



Institut de France
Académie des Sciences.

Paris, le 17 décembre 1850.

Le Secrétaire perpétuel de l'Académie,
pour les Sciences Mathématiques.

Monsieur,

J'ai l'honneur de vous informer que l'Académie des Sciences, dans sa Séance Publique du Lundi 16 de ce mois, vous a décerné, dans le Concours des Prix d'Astronomie, (fondation Lalande), le Prix de l'Année 1849, pour la découverte que vous avez faite le 14 Avril 1849, d'une nouvelle Planète, qui a été nommée hygie.

Dans la même Séance l'Académie, vous a décerné, de moitié avec Mr. Hind, le Prix d'Astronomie de l'Année 1850, pour les deux nouvelles planètes que vous avez découvertes les 11 Mai et 2 novembre 1850, dont l'une a été nommée Parthénope.

Je saisis avec empressement, Monsieur, cette

A Monsieur de Gasparis,
Attaché à l'Observatoire de Naples.

Figure 5: Diploma of the *Prix d'Astronomie* for the discoveries of Hygiea and Parthenope signed by Francois Arago (courtesy: National Library of Naples, Manuscripts and Rare Section).

Lazzaro Together with the knighthood granted to Giovan Battista Donati (1826-1873) of Florence and Giovanni Virginio Schiaparelli (1835-1910) of Milan,

Figure 6: Sketch for the discovery of Beatrice in 1865 by Luigi Borgomainerio published under the pseudonym of Don Ciccio in the *Strenna dello Spirito folletto* of 1866. (courtesy: Biblioteca di Storia Moderna e Contemporanea - Rome).

the three astronomers formed "a beautiful triad of illustrious discoverers of celestial bodies, to whom the Sovereign today attested his consideration" (Sella 1861).

The political role played by de Gasparis and Capocci in the new Italian institutions came to a partial renewal of the scientific instrumentation of the Neapolitan Observatory. In 1861 the two senator-astronomers persuaded De Sanctis, minister of Public Education, to assign the necessary funds for the purchasing of a new telescope: "I come to beg you to provide this Observatory, without further delay, with an achromatic telescope with an objective from five to six inches of aperture, specially mounted, to be used in the search for new planets and comets... since de Gasparis had to use it above all in these searches in which he achieved so much celebrity" (Capocci 1861). The Ministry granted a special fund for the purchase of an equatorial telescope which was commissioned from the Merz company of Munich. The first Italian telescope, with an objective aperture of 13.5 cm and a focal length of 220 cm, arrived in Naples in September 1863 and was housed by de Gasparis in the east dome of the Observatory (Gargano 2017, pp. 116-122).

Appointed as director of the Capodimonte Observatory in 1864, de Gasparis made every effort to strengthen the Institute and gave new impetus to meteorological and geomagnetic measurements. Although he was a pure celestial mechanic, he broadened the scientific horizons of the Observatory towards the astrophysical studies of the stars, supporting the foundation of the "Società degli Spettroscopisti Italiani", the first scientific society dedicated to the new science (Chinnici 2008). In 1869 de Gasparis managed to obtain further substantial funding to purchase a new meridian circle with an aperture of 165 cm and a focal length of 202 cm built by the Repsold firm of Hamburg (Gargano 2017, pp. 128-130). Furthermore, in parliament, he worked hard to ensure that the Chamber of Palazzo Madama allocated the necessary funds to the Brera Observatory to purchase a new telescope for Schiaparelli's studies on the cartography of Mars. In this circumstance, De Sanctis praised the astronomer of Capodimonte for having given a so noble speech that it seemed to hear the music of the stars mentioned by Pythagoras, and for having transformed the discussion on a bill into a scientific party. "Already famous for ancient discoveries, the old astronomer… demonstrated a high nobility of mind, he took the young Schiaparelli under his patronage... and said to him: Italy is not rich enough to provide you and me a telescope... get it you, and give prestige to Italy with other discoveries" (Taddei 1878). The renewal of the instrumentation of the Capodimonte Observatory continued throughout the 25 years of direction. The volume "*Sullo stato del R. Osservatorio di Capodimonte*", published by de Gasparis in 1883, represents the direct evidence, sober and plain, of scientific research and instrumentation of the largest among the Italian observatories of the time.

However, his celebrity went beyond the boundaries of astronomy, finding space among the ordinary people and writers who dedicated numerous poems to him. The scientific value, unanimously acknowledged to the Capodimonte astronomer, is testified by many essays. The songs and stanzas written for the discovery of Egeria by Giovanni Chiaia (1799-1888), poet and magistrate, the ode for Beatrix by the poet Giovanna Milli, the sonnet by Giovambattista de Santis, a priest from Rieti, and the works dedicated to him by Angelo Camillo De Meis (1817-1891) and Vincenzo Caracciolo (*1853), nephew of the 4th prince of Marano, are a vivid proof of the celebrity of the astronomer and his discoveries. The "Giornale del Regno delle due Sicilie" and the humorous newspapers of the time, such as "Arlecchino, Il lampione, Il palazzo di cristallo", and "Lo spirito folletto" published many articles on discoveries and celebrity of de Gasparis. Countless joking and burlesque articles testify to his popularity (Fig. 6). He became the protagonist of puzzle games and was appointed as Minister of Foreign Affairs together with Plato in Education and Giuseppe Verdi in the Navy (Dispaccio Elettrico, 1861, p. 376). Commenting on the poor performances of the Marchand and Ellenberg's theatre, an editor of the magazine "Il palazzo di cristallo" wrote that "this mechanical theater from the Netherlands wants to create a de Gasparis audience, educate the spectators, and introduce them into the secrets of the Sun, Moon and other planets". The same journal reports that "de Gasparis has found a planet at the bottom of the sock" and "romantics go to sleep in Capodimonte within range of de Gasparis's telescope" (Il Palazzo di cristallo, 1856, Vol. I, pp. 126, 606 & 755). The astronomer is mentioned in the comments for the construction of new railways: "De Gasperis will be able to use it for free with the agreement to discover some planet from the observatory of the Moon to be engaged as prima donna at the S. Carlo theater" (Il Palazzo di cristallo, 1856, p. 114), and among the things to do in Naples: "Demolish the museum to make the telescope of de Gasparis easily visible from via Toledo" (Il Palazzo di cristallo, 1856, Vol. I, p. 126). The magazine "La Favilla" reports a story that seems to have come out of the book “Cuore” by De Amicis: poor Celestino Romaniello, a talented orphan student, caused so much emotion during the exams that “the distinguished Mr. de Gasparis invited that dear boy at the observatory for a meeting, assuring him that he would especially recommend it” (Un bravo fanciullo, 1863). Furthermore, with the discovery of Parthenope, the author of an article craved de Gasparis's mastery of tracking down “new planets in the sky, while I on the ground with the lens in my eyes, now with the binoculars, I wander around Toledo in vain, I wander around Chiaia in vain. Dear de Gasparis, tell me the recipe for making discoveries, lend me your telescope. As soon as I have discovered a worthy planet… I will call it Neapolitan beauty!” (Il Palazzo di cristallo, 1856, p. 697). And finally, at the hypothetical announcement of Le Verrier, “the astronomer who foresees the planets from his desk observatory that a hundred planets, between Mars and Jupiter, would have been discovered in 1866… de Gasparis hurried to Capodimonte to discover about fifty of these hundred… [because] when de Gasparis hoists the incredible telescope, the firmament trembles, and the planets appear themselves in front of its lenses”. After all, as Adolfo de Cesare (1828-1901) wrote in the journal, “the planets will remain calm and not be afraid of being denounced by de Gasparis's terrible telescope as long as the fog will be permanent even at night on the proscenium of the sky” (Il Palazzo di cristallo, 1856, Vol. I, p. 558 and 1013).

Conclusions

The reconstruction work of the scientific correspondence of Annibale de Gasparis made it possible to census and catalog more than 500 letters, exchanged with over 120 correspondents and distributed in around 40 Italian and foreign cultural institutions. This historical research was presented in Pisa in September 2019 during the xxxix annual congress of the Italian Society of History of Physics and Astronomy and on the occasion of the Annibale de Gasparis Workshop, held in Naples to celebrate the second centenary of the astronomer's birth (Gargano 2020). The study of the letters has continued over time with the analysis of the themes and the discovery of new documents and archival collections, such as the one identified at the National Library of Naples (Redazione Media Inaf 2022). This study helped to understand and clarify de Gasparis' scientific relationships and interests and brought out the atmosphere in more detail over the years of his cosmic explorations. To highlight all recognized documents, a virtual archive of the Annibale de Gasparis Correspondence was created that can be consulted on the INAF portal for cultural heritage at the address: tinyurl.com/correspondence-degasparis.
The letters are characterized by an extreme synthesis and by analyzing them four main fields can be identified: astronomical observations and discoveries, renewal of the Observatory's instrumentation, studies of celestial mechanics, and familiar topics. In the years of his discoveries, the correspondence contains annotations and observational data, but never illustrations or sketches. The only exceptions are a letter to Le Verrier on the observation of Jupiter in 1864 and a communication from the University of Naples recycled first for administrative use and then for a sarcastic drawing on the Turkish-Russian war of 1877-78. In addition to a sibylline verse that

reads: "I have this fanatic smell / in my big pocket / against the fetid smells of my friend [Abbott?] / which [who?] always". Besides the scientific interests outlined in the previous paragraphs, from the few family letters, Annibale de Gasparis appears as an affectionate and considerate man towards his wife and children[17], as well as reserved and discreet about his thoughts. Even in the tensest situations, he didn't indulge in comments or judgments above the lines. "Absorbed in my little family in which, with whom and for whom I live, I don't take trouble at all of the affairs of others (even if they were people of a close acquaintance or kinship)" (de Gasparis 1852). A man of "small stature" and with a beard that he wore "almost entirely" (de Gasparis 1848), Annibale de Gasparis was a simple and gentle person, far from "luxury, parties and pompous receptions". He liked theater, the light and popular one staged at the Partenope Theater and San Carlino Theater, where a young Eduardo Scarpetta (1853-1925) performed, and the comic opera in music and prose of the Mercadante Theater in Largo delle Pigne.

In 1889 the signs of progressive paralysis and physical suffering forced him to abandon all public office. Although also suffering from almost total loss of sight, de Gasparis found the only relief in his youthful passion for classics, reciting Virgil and Ossian by heart (D'Ovidio 1892). The day after the death of Annibale de Gasparis, which took place on 21 March 1892, the president of the Senate, Domenico Farini (1834-1900), paid homage "to his lofty ingenuity, to his sublime calculations, to his mind, admirably suited to the most abstruse speculations, to the scientist accustomed to pointing his gaze and intellect upwards" (Farini 1892).

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[17] In 1848 he married Maria Giuseppa Russo (*1825) and had nine children: Teresa (1850-1856), Eleonora (1852-1856), Alberto (*1853), Aurelio (*1860), born on the same day as Garibaldi's triumphal arrival in Naples, Anselmo (1869-1871), Angela, Amedeo, Chiara, and Maria. It is noteworthy that the names of de Gasparis's sons begin with the letter A, like his name and that of his father Angelo.

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Nodules and chert layers in the Ichtyolitic Limestones Formation of Civita of Pietraroja (Southern Apennines, Italy). A genetical model

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Abstract

The present paper concerns the study of the silicization processes occurring in the "Ichthyolitic Limestone" outcropping at the Civita of Pietraroja (Benevento), in the Matese Mountains. (Southern Apennines, Italy). Previous Authors provided descriptions of these deposits, without proposing a specific genetic model. Different types of cherts were observed, sampled, and studied in optical microsocopy, characterizing their sedimentological features, the contained microfauna, and their state of conservation. Observations confirm that silicization is penecontemporary to the sedimentation of the fine-grained lagoonal limestones. Specifically, to explain silicization processes in limestones, the following paleo-environmental context of the Pietraroja lagoon, and the surrounding areas, must be taken into account: a first source of primary silica may have been located in the emerged areas overlooking the lagoon, where carbonate weathering processes, leading to the formation of bauxites, had probably begun. This leaded to the accumulation of residual materials (including siliceous ones). The "Orbitolina Level of the Campania" too, derived at least in part from the accumulation of pyroclastic materials, slightly older than the "Ichthyolitic Limestones" and cropping out in the area in the uppermost Aptian-lower Albian, could be regarded as an additional source of primary silica. The richness in silica of this neritic-lagoon environment could consistently have supported the development of siliceous sponge colonies, whose spicules, originally consisting of Opal A, are often very abundant in lagoonal sediments. According to the described conditions, a mixing zone between fresh meteoric and continental waters and lagoonal marine waters, was very likely present in the sediments bordering the lagoon and within it. In accordance with a previously proposed model, the dissolution of sponge spicules (Opal A, biogenic silica), and the reprecipitation of silica phases as colloidal gels within the carbonatic sediments could give rise to silicizations in the form of nodules and layers.

Keywords: lower Cretaceous, chert, lagoonal environment, stratigraphy, sedimentology, Southern Apennines.

Riassunto

Il lavoro prende in considerazione le silicizzazioni presenti nei "Calcari ad Ittioliti" affioranti alla Civita di Pietraroja (Benevento), nel Matese orientale (Appennino Meridionale, Italia). Precedenti Autori ne hanno fornito descrizioni, senza però proporre uno specifico modello genetico. Le diverse tipologie di selce osservate sono state campionate e studiate in sezione sottile, caratterizzandone le litologie sedimentarie, le microfaune e le loro condizioni di conservazione. Le osservazioni confermano che la silicizzazione è penecontemporanea alla sedimentazione lagunare. Riguardo la genesi delle silicizzazioni nei calcari, considerando il quadro paleoambientale della laguna di Pietraroja e delle aree a contorno, vengono individuate come fonti primarie di silice le aree emerse prospicienti dove, con ogni probabilità, erano iniziati i processi di "*weathering*" dei carbonati che condurranno alla formazione di bauxiti, con accumulo di materiali residuali, tra cui quelli silicei. Il "Livello a Orbitoline della Campania", in parte a matrice piroclastica, poco più antico dei Calcari ad Ittioliti, ed evidentemente affiorante o subaffiorante nell'area nell'Aptiano terminale - Albiano basale, poteva costituire una ulteriore fonte di silice primaria nei terreni a contorno della laguna. La ricchezza in silice di tale ambiente neritico-lagunare poteva pertanto favorire lo sviluppo di colonie di spugne silicee, le cui spicole, originariamente costituite da opale A, sono abbondantissime nei sedimenti lagunari dei Calcari ad Ittioliti di Pietraroia.
Nelle condizioni descritte, una zona di mixing tra acque dolci meteoriche e continentali e acque marine lagunari, era certamente presente nei sedimenti a contorno della laguna e nella laguna stessa. In essa potevano avvenire i processi di soluzione della silice biogenica (opale-A) derivata dalle spicole di spugne e la riprecipitazione di essa in forma di gel colloidali nei sedimenti carbonatici, formando noduli e letti di selce sui fondali lagunari.

Parole chiave: lower Cretaceous, selce, laguna, stratigrafia, sedimentologia, Appennino Meridionale.

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Introduction

The Civita of Pietraroja (Fig. 1) is a monocline structure which is part of the Matese Mountain group. It is located at the eastern edge of this fold and thrust belt.

The Lower Cretaceous stratigraphic succession consists of about 320 meters of dolomitic limestone and limestone, finely detrital, sometimes pseudoolitic, in layers and banks. In the upper part of the sequence the “Orbitolina level”, Upper Aptian in age, is present (Cherchi *et al.*, 1978). The Ichthyolitic Limestone Formation *(Plattenkalk*) is a lower Albian, thin layered level, in the uppermost part of this succession, heteropic with limestone in massive layers, in neritic facies of more open carbonate platform (D'Argenio, 1963; Freels, 1975; Bravi & Garassino, 1998). It is constituted by brown and grey, thin and fine-grained layers showing conchoidal fracture, interbedded with chert layers and nodules and thinly laminated marls (D'Argenio, 1963; Catenacci & Manfredini, 1963; Freels, 1975; Bravi, 1997). D’Argenio (1963), Freels (1975), Bravi & Garassino (1998), in contrast to Catenacci & Manfredini (1963) and Carannante *et al*.

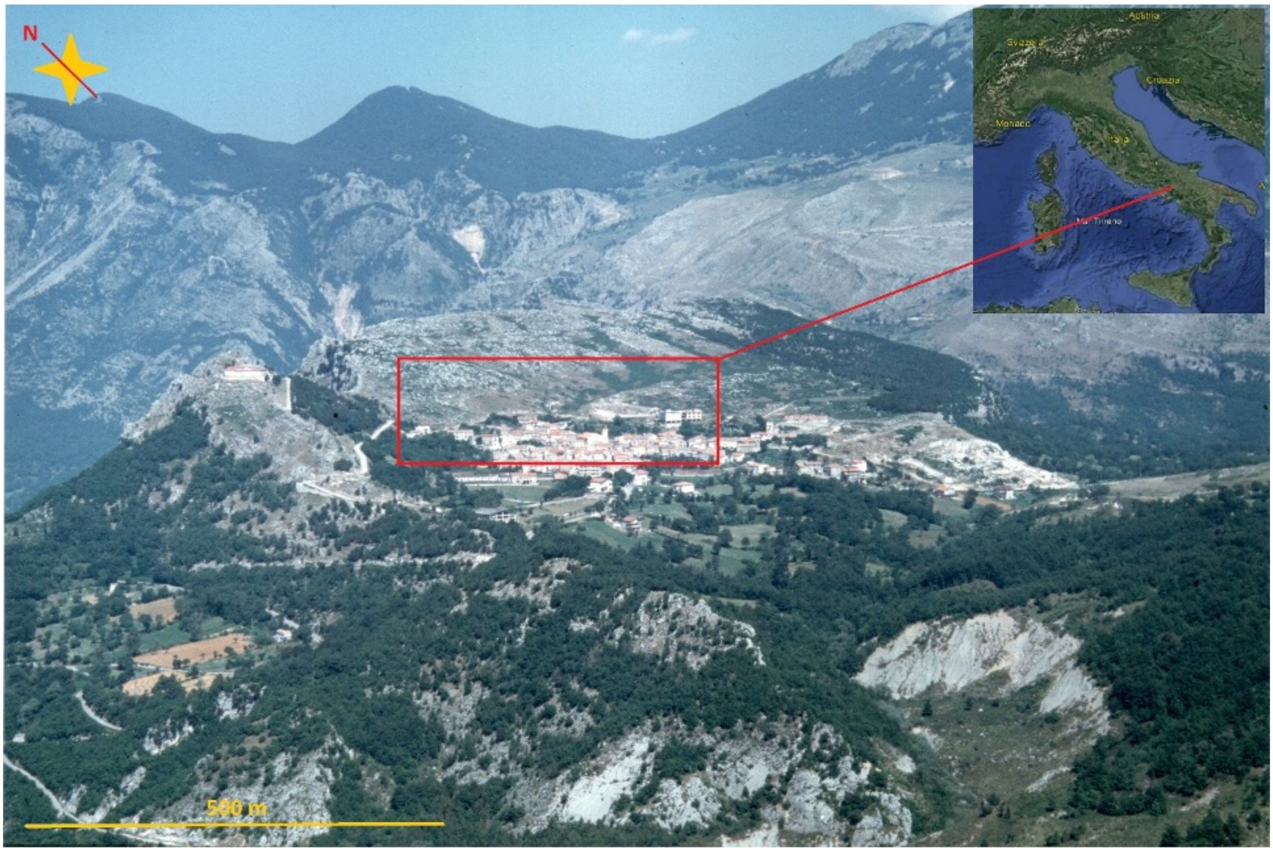

Figure 1: Location of the study area, Civita of Pietraroja (Matese Mts., Southern Apennines, Italy).

(2006), considered the Ichthyolitic Limestone of Pietraroja as deposited into a shallow lagoon environment. The chert in the Ichthyolitic calcareous formation, is represented by nodules, angular clasts, and layers. Considering that chert layers are mostly found in deep marine sediments, these thin chert layers in the Ichthyolitic Limestone of Pietraroja, sometimes very widespread (Figs. 2A-D), represent a peculiarity. The above-mentioned Authors provided descriptions of these cherts but, up to now, without hypothesizing a specific genetical model. The purpose of this paper is to explain their genesis, in a paleoenvironmental and sedimentary context such as that of the lagoon basin, where the Ichthyolitic Limestones of Pietraroja were deposited.

The Uppermost Aptian – Lower Albian local paleoenvironment

During lower Albian, a marked low-stand phase of the sea level determined extensive emergences of land and the formation of lagoons bordering the emerged areas, such as the lagoon of Pietraroja, within the carbonate platform area, today represented by the Eastern Matese Mts. (Bravi, 1995). In this lagoon, animals as the dinosaur *Scipionyx samniticus* (Dal Sasso & Signore, 1998; Dal Sasso & Maganuco, 2011) and other reptiles, together with land plants as *Frenelopsis* sp. and *Brachyphyllum* sp., (Bartiromo *et al.*, 2006; Bartiromo *et al.*, 2012; Bartiromo, 2013) were occasionally transported and fossilized, along with the lagoonal fauna (fish and crustacean). On these lands, most likely freshwater reservoirs (marshy areas, small streams) transported in the lagoon: 1) faunal and floristic elements as fish of brackish or freshwater environment (e.g., *Pleuropholis* and *Lepidotes*) and 2) remains of land plants, oogons of Carophytes (Bravi, 1988; Bartiromo *et al.*, 2006, 2012).

This paleoenvironmental framework implies the existence of a mixing zone between continental fresh waters and salty (probably temporarily oversalted) waters of the lagoon. On this basis, we propose an in-depth study and a justification for the chert nodules and layers presence in the Ichthyolitic Limestones of Pietraroja.

Knauth (1979) proposed a model of chert genesis in marine shallow water limestones. This paper stands with this hypothesis, due to the paleoenvironmental characteristics of the Pietraroja Ichthyolitic Limestone depositional basin that, in accordance with D'Argenio (1963), Freels (1975), Bravi & Garassino (1998), can be considered as effective.

Knauth (1979) theorizes a geological situation in which meteoric water can mix with sea water into the mixing zone, in coastal marine environment, in sediments enriched of silica (Opal A) due to the siliceous organisms remains (Fig. 3A). The mixing of fresh and salt water can produce silica supersaturated waters, due to high solubility of biogenic Opal A, but undersaturated in calcite and aragonite (Fig. 3B).

Materials and methods

This work involved a first phase of field study and sampling, where main formations present in the "Civita of Pietraroja" area and their relationships were studied. Based on pre-existing investigations and geological maps (Freels 1975), we proceeded to add further data and to identify and describe the

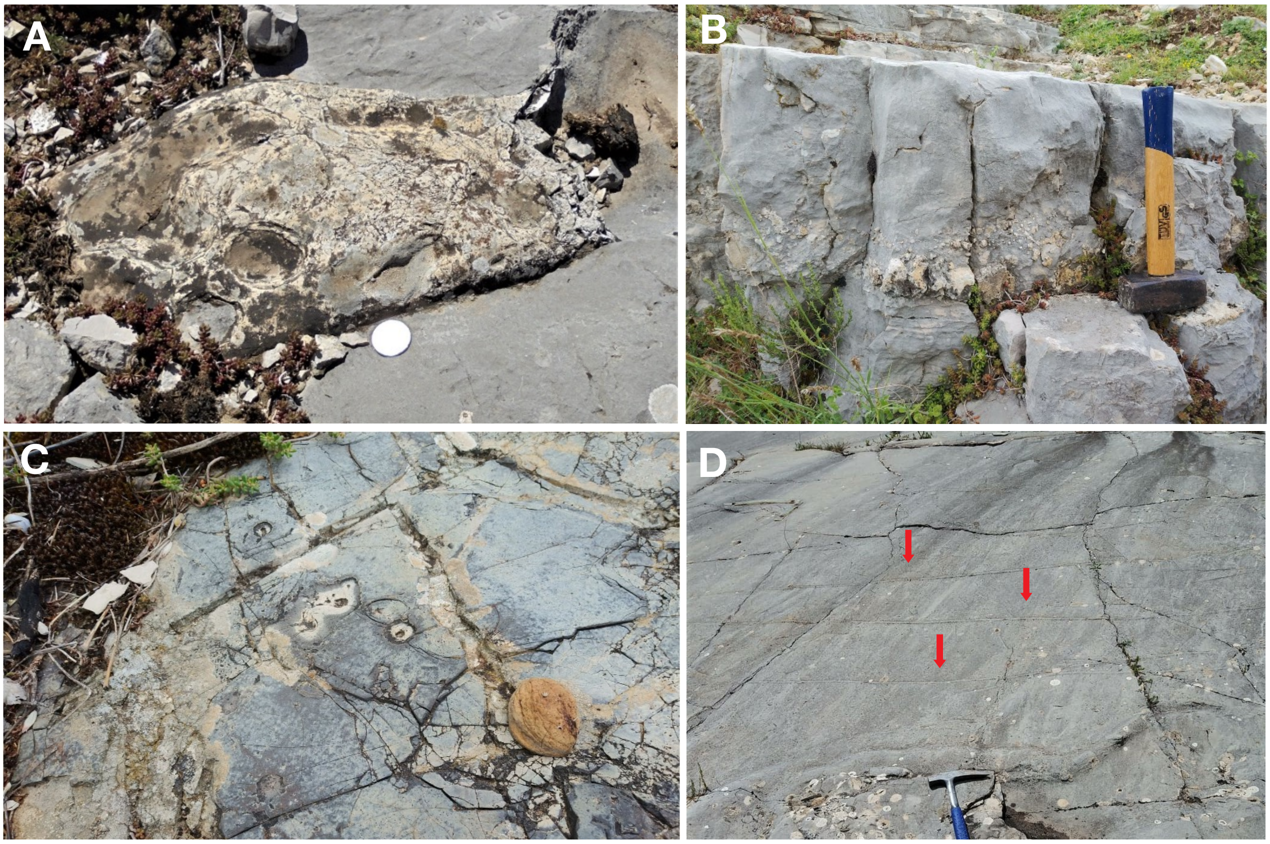

Figure 2: A) Siliceous nodule of lobed shape. "Collapse" structures can be observed on its surface, due to the leakage of gas (H2S) from the inside of the nodule, and the consequent collapse of the roof of the cavity that contained it. Dimensional reference at the bottom, under the nodule: 1euro coin. **B)** Layers of Ichthyolitic Limestones (upper part of the sequence), with chert scattered as angular clasts, at the base of the layer. **C)** Centimeter "gas-pits" on the surface of a chert bed, fractured into polygons for syneresis. Basal layer of the Ichthyolitic Limestones, locality: "Le Cavere". The walnut shell in the lower right is a dimensional reference. **D)** Long lineations on a metric scale (indicated by arrows), with inverted V section, present on the basal calcareous layer of the Ichthyolitic Limestones. They were produced by the "sinking" of the overlying siliceous layer, broken into large blocks in the early stages of the syneresis process. Locality: "Le Cavere".

main chert formations (nodules, beds, polygons, and clasts immersed in the limestone layers), specifying their characteristics in terms of position and sampling them. Samples from the whole stratigraphic succession of the Ichthyolitic Limestone formation (about 8 meters; see Fig. 4) cropping out at "Le Cavere" locality and its surroundings, were observed in optical microscopy to describe their fossil content and their sedimentological microfacies (Tab. 1).

Some samples (Spic1, Spic2, PS 12A, P5, among the others; see Tab. 1) were prepared for chemical and petrographic analyses. In these samples, sponge spicules were still clearly evident and often, very abundant. The purpose of these analysis was to verify the composition of the spicules, since these could potentially be of calcareous origin (Calcisponges), instead of siliceous (Silicosponges).

Mineralogical analyses were performed by X-ray powder diffraction (XRPD) using a Malvern Panalytical X'Pert Pro diffractometer

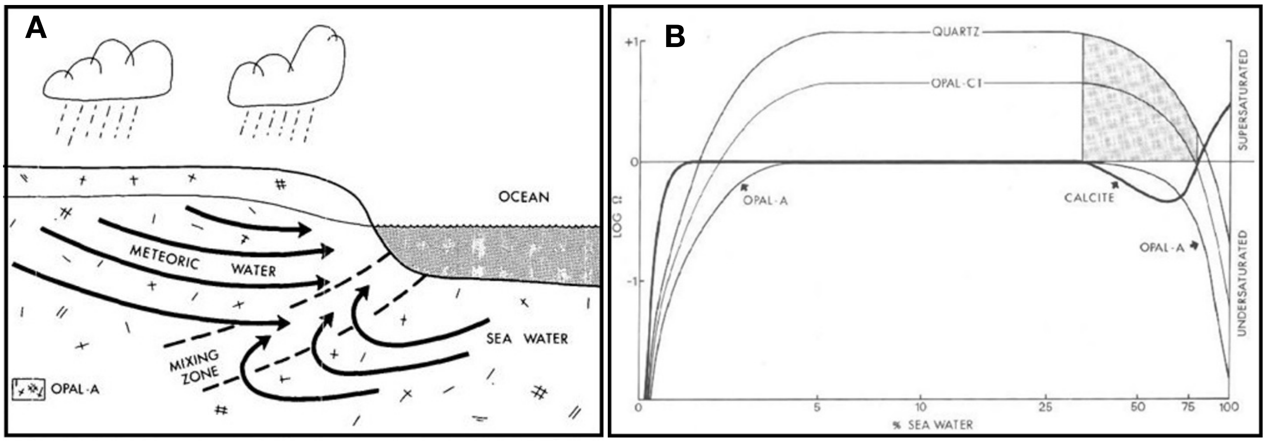

Figure 3: A) Schematic model of the mixing zone in which the silicization processes of the sediments take place. (From Knauth, 1979). **B)** Solubility relationships of calcite and silica in mixed meteoric-marine ground waters closed with respect to CO_2. The saturation state is expressed in terms of log Ω, where Ω = ratio of the ion activity product to the mineral equilibrium constant. A solution is saturated with respect to the mineral phases when log Ω = 0. Positive values of log Ω indicate supersaturation, and negative values indicate undersaturation. In the hypothetical case depicted, mixing of meteoric and marine waters has produced ground water simultaneously undersaturated with respect to calcite and supersaturated with respect to crystalline silica. The shaded zone defines conditions in which it is thermodynamically possible for silica to replace carbonate. The spacing of abscissa increments is arbitrary. (Drawing and caption from Knauth, 1979).

equipped with a RTMS X'Celerator and a X'Pert High Score Plus 3.0c software.
Operating conditions were: CuK radiation, 40 kV, 40 mA, 2Θ range from 4 to 70°, equivalent step size 0.0172°, equivalent counting time 120 s per step. Powders with grain size <10 μm were obtained using a McCrone micronizing mill (agate cylinders and wet grinding time of 15 min). An Al_2O_3 internal standard (1 μm, Buehler Micropolish) was added to each sample (20 wt.%). Micro-textural observations and quantitative micro-chemical analyses were carried out by Scanning Electron Microscopy, equipped with an Energy Dispersive detector (SEM/EDS; Zeiss Merlin VP Compact and JEOL JSM-5310, respectively coupled with Oxford Instruments Microanalysis Units X-Max and INCA X-act detectors. Measurements were performed with using a stream pulse processor (15-kV primary beam voltage, 50–100 A filament current, variable spot size, from 30,000 to 200,000x magnification, 20 mm WD and 50 s net acquisition real time). INCA Energy software was employed using XPP matrix correction scheme and pulse pile up correction. Quant optimization was carried out using cobalt (FWHM–full width at half maximum peak height- of the strobed zero = 60–65 eV). Smithsonian Institute and MAC (Micro-Analysis Consultants Ltd., Saint Ives. UK) standards were used for calibration using these phases: diopside (Ca), fayalite (Fe), San Carlos olivine (Mg), anorthoclase (Na, Al, Si), rutile (Ti), serandite (Mn), microcline (K), apatite (P), fluorite (F), pyrite (S) and sodium chloride (Cl). Precision and accuracy of EDS analyses are reported in Rispoli *et al*., 2019.

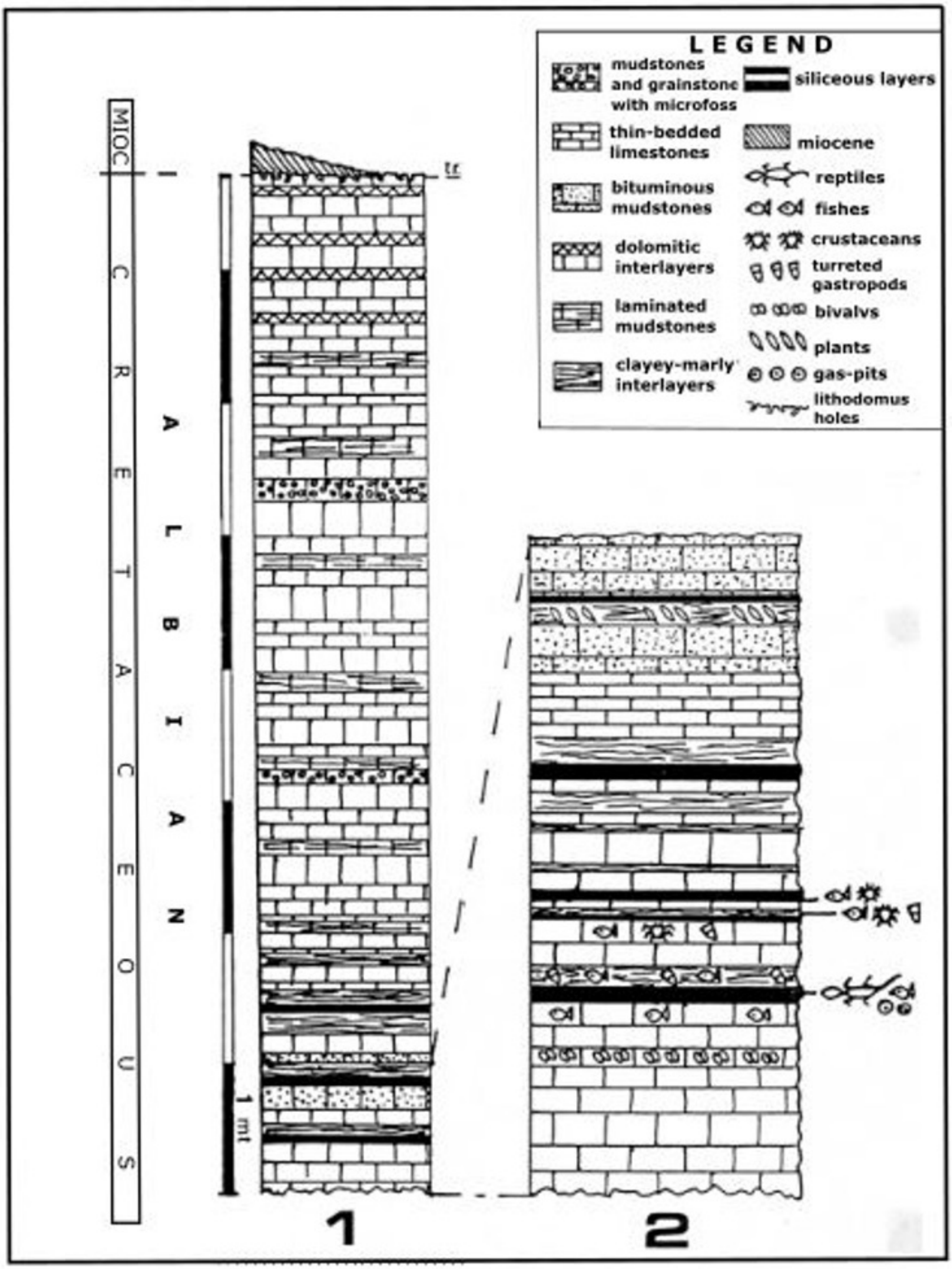

Figure 4: Detailed stratigraphic succession of Ichthyolitic Limestones in "Le Cavere", Civita of Pietraroja **(1)**. The detail of the stratigraphic column **(2)** displays the alternation of calcareous, siliceous, and calcareous-marly-clayey laminated layers, as well as their most characteristic fossiliferous content. From: Bravi, 1997.

Table 1: Main characteristics of the selected samples.

SAMP	LITHOLOGY (DUNHAM)	FOSSILIFEROUS CONTENT	NOTES / OTHERS	LOCATION
PLS1A	G (coarse)	Unrecognizable silicized foraminifers	High degree of silicization. Fractured chert.	Plattenkalk base, "Le Cavere"; chert bed.
PLS1B	P	Miliolids	High degree of silicization. Brownish organic matter remains.	Plattenkalk base, "Le Cavere"; chert bed.
PLS1C	P	Miliolids	High degree of silicization. Brownish organic matter remains.	Plattenkalk base, "Le Cavere"; chert bed.
SPIC1	P (fine)	Sponge spicules. *Thaumatoporella* sp.; *Glomospira* sp.; dwarf foraminifers fauna.	Simulated dwarfism of faunas due to the selection of granules. Brownish organic matter remains.	"Le Cavere" Plattenkalk outcrop.
SPIC2	P - W	Sponge spicules. Dwarf foraminifers (miliolids), *Glomospira* sp., textulariids; valulinids; *Thaumatoporella* sp.	Normal graded. Lamination.	"Le Cavere" Plattenkalk outcrop.
SPIC3	W – p (fine)	Sponge spicules; fragments of molluscs; dwarf foraminifers, *Thaumatoporella* sp.	Normal graded. Simulated dwarfism of faunas due to the selection of granules.	"Le Cavere" Plattenkalk outcrop.
PS2	P - G	Foraminifer (miliolids); ostracods	High degree of silicization.	"Le Cavere" Plattenkalk outcrop.
PS4	P (fine)	Dwarf valvulinids and miliolids; shell fragments.	Normal graded. Lamination.	"Le Cavere" Plattenkalk outcrop.
PS4.2	P	Fragments of fossil fish.	High degree of silicization.	"Le Cavere" Plattenkalk outcrop.
PS7	W (dark laminae); P/G (clear laminae)	W: Miliolids; *Thaumatoporella* sp.; textulariids; *Cuneolina pavonia*; *Pseudonummoloculina* sp.; sponge spicules. P-G: fragments of molluscs; *Thaumatoporella* sp.	Normal graded. Lamination.	"Le Cavere" Plattenkalk outcrop.
PS7.2	P (coarse at the (base). W (top)	*Thaumatoporella* sp.; ostracods, fragments of molluscs.	Lamination.	"Le Cavere" Plattenkalk outcrop.
PS8	G - P	*Cuneolina* sp.; textulariids; *Pseudonummoloculina* sp.; *Cuneolina pavonia*, *Sabaudia minuta*; little orbitolinids (*Paracoskinolina tunesiana*); fragments of molluscs.		"Le Cavere" Plattenkalk outcrop.
PS9	P - W (fine)	Oriented sponge spicules; dwarf textulariids; miliolids; *Glomospira* sp., dwarf valvulinids.	Simulated dwarfism of faunas due to the selection of granules.	"Le Cavere" Plattenkalk outcrop.
PS10	W - M (dark laminae);P-G (clear laminae).	*Cuneolina* sp	High degree of silicization.	"Le Cavere" Plattenkalk outcrop.
PS11	P	*Cuneolina pavonia*; *Thaumatoporella* sp.; miliolids; textulariids; *Glomospira* sp; *Debarina hahounerensis*, *Pseudonummoloculina* sp., Sponge spicules.		"Le Cavere" Plattenkalk outcrop.
PS12	M?		Nodules in limestone beds. Microcrystalline, high degree of silicization. Unrecognizable primary structure. Brownish organic matter remains.	Stratigraphically higher in "Le Cavere" stratigraphic sequence.
PS12A	W?	Sponge spicules. Unrecognizable, silicized foraminifers.	High degree of silicization. Unrecognizable primary structure.	Plattenkalk base, "Le Cavere"; chert bed.
PS12B	M?		High degree of silicization. Unrecognizable primary structure.	Nodules along the road. Out from "Le Cavere" outcrop.
PS12T	W – P (fine)	Sponge spicules. *Pseudonummoloculina* sp., miliolids; orbiltolinids in chert; *Paracoskinolina tunesiana*, valvulinids; *Thaumatoporella* sp., textulariids; *Cuneolina pavonia*; *Nezzazzatinella picardi*.		"Le Cavere" Plattenkalk outcrop.
P5	M	Sponge spicules.		"Le Cavere" Plattenkalk outcrop. Upper part.

Results

Chert in the Ichthyolitic Limestones formation is represented by layers, nodules, and angular fragments dislocated within the limestone beds. Layers are compact, thin bedded and parallel to the limestone layers. Nodular structures are ellipsoidal or lobed in shape, sunk in the underlying limestone layer, due to their greater specific weight. Their central part is more silicified, while edges are richer in carbonate component. Sometimes chert is fragmented in angular or polygonal clasts, giving rise to breccia-like facies. According to D'Argenio (1963), fragmentation predates incorporation in limestones. More nodules are observed in the marginal areas of the basin outcropping at "Le Cavere". Conversely, thin and continuous chert layers are present in parts corresponding to a more distal and deeper area, characterized by a flat bottom (Bravi, 1997). Moreover, the higher specific weight of silica could have favoured gravitational accumulation of siliceous gels (e.g., "sliding" from the steeper and marginal areas of the basin towards the deeper areas), producing even more silica saturation within the sediments and in waters present at the "basinal" flat bottom zone. Metric-scale slumping are present near marginal areas of the Ichthyolitic Limestone basin. These likely caused sediment to be transported towards its depocenter, and influencing the transport of chert, thus originating mild turbidity currents (laminations; according to Freels, 1975; Bravi & Garassino, 1998).

Cherts sampled at "Le Cavere" outcrop show macro-sedimentary structures such as gas-pits (shallow water-depth indicators), syneresis polygons and often well-preserved microstructures, such as laminations (Figs 2C, 2D. Shrock, 1948; Twenhofel, 1950; D'Argenio, 1963; Freels, 1975; Bravi, 1997; Bravi & Garassino, 1998). Nodules sampled in the marginal areas and in the upper part of the Ichthyolitic Limestones sequence, often show collapse structures on surfaces (Fig. 2A). The samples have been subdivided into three main groups, using their distinct microfacies: 1) fine-grained, microlaminated facies; 2) non-laminated facies, with generally homogeneous microcrystalline structure; 3) non-laminated, coarse-grained facies (Fig. 5).

Microlaminated samples (Figs. 5C, 5D) show micro-turbidity and millimetric lamination with normal gradation (packstone-grainstone at the lamina base, wackestone-mudstone up to the lamina top). Within the coarse-grained part, a microfauna and microflora (miliolids, valvulinids, textulariids, *Glomospira* sp., *Thaumatoporella* sp., fragments of molluscs, sponge spicules) is present. Silicization affected limestone laminae after their deposition, due to the precipitation of siliceous gel in the pores of the sediment.

Non-laminated facies group is mostly found within chert nodules. Strongly silicified facies (Fig. 5E) and partially silicified facies (Fig. 5F) are present in this group. In the first case, an unrecognizable microfauna and brownish organic matter are also present. In the second case, foraminifer shapes can be clearly recognized, but whenever silicization process is more intense, they are completely replaced by silica and therefore transparent (e.g., miliolids).

In the last group (coarser-grained facies as grainstone and grainstone-packstone), foraminifers are abundant (Figs 5A, 5B). Strong silicization is present, as coarser particle size influenced permeability of the sediment, permitting a good circulation of silicizing fluids.

EDS chemical composition of investigated materials (Fig. 6) confirmed the observations from optical microscopy and the results basically show SiO_2 as the solely constituent of the rock portions attributable to the spicules (Tab. 2; Fig. 6); the surrounding matrix, on the contrary, appears to be totally composed by calcite (Tab. 2), as also evidenced by XRPD analysis (Fig. 7), with a very weak magnesian component that appears to be enriched in the sample P5 (MgO = 0.92 wt %), compared to the one surrounding the spicules (MgO = 0.41-0.59 wt %). As above reported, XRPD analyses evidenced the presence of calcite along with a major component constituted by quartz.

Discussion

The paleoenvironmental model of the Ichthyolitic Limestones of Pietraroja poposed in this paper, is the one of a typical shallow lagoon, with little exchange with the open sea, surrounded by emerged areas, subjected to carbonate weathering, soil formation and residual accumulation of iron and aluminium hydroxides, along with silica oxides (initial bauxitization processes). The "Orbitolina level", with its amount of volcanic components as an additional source of silica, was also an element of the uppermost Aptian – lower Albian terrains cropping out in the nearby environment. With this setup, a mixing zone between fresh and sea waters is very probable. In a warm-humid subtropical climate, rainfalls are also frequent, thus contributing with more, meteoric, fresh waters. Emerged lands were also very extensive, considering that they hosted flora of the *Phlebopteris* type (Bartiromo *et al*., 2006), *Frenelopsis*, and freshwater plant *Montesechia vidali* (Bartiromo *et al*., 2012), as well as reptiles such as the dinosaur *Scipionyx samnitucus* (Dal Sasso & Signore, 1998; Dal Sasso & Maganuco, 2011) at the apex of the food chain. There are also brackish or freshwater fossil fish such as *Lepidotes*, *Pleuropholis decastroi* (Bravi, 1988), beholding the contribute of fresh water to the lagoon.

In this context, we propose that one of the primary sources of silica was the weathering of silicatic material occurring above carbonates, as testified by the occurrence of bauxites in the "Regie Piane" locality (no further than 2 km from Civita of Pietraroja). Their presence indicates that there was an emerged area (carbonates) nearby, subject to weathering under a sub-tropical climate and intense rainfalls (Bardossy & Aleva, 1990). The formation of bauxite, very common during the Aptian-Coniacian, in the Apennine shelf areas (D'Argenio & Mindszenty, 1995), has been able to precipitate crystal phases such as gibbsite, diaspore, hematite and goethite. Bauxites were formed in part by pyroclastic materials (carried by the wind) which, covering the carbonate platform, were subjected to laterization and remobilization (D'Argenio & Mindszenty, 1995; Boni *et al*., 2012). Karst areas, with excellent drainage, allowed "desilicification" of the bauxites, protecting them from erosion, and provided further source of silica (according to Mondillo *et al*., 2011). Another source of silica can be considered the volcanic, detrital minerals of pyroclastic origin, occurring in the "Orbitolina level", (mineralogical associations with feldspar, muscovite, olivine, titanite, possible serpentine talc phase) (Mondillo *et al*., 2011).

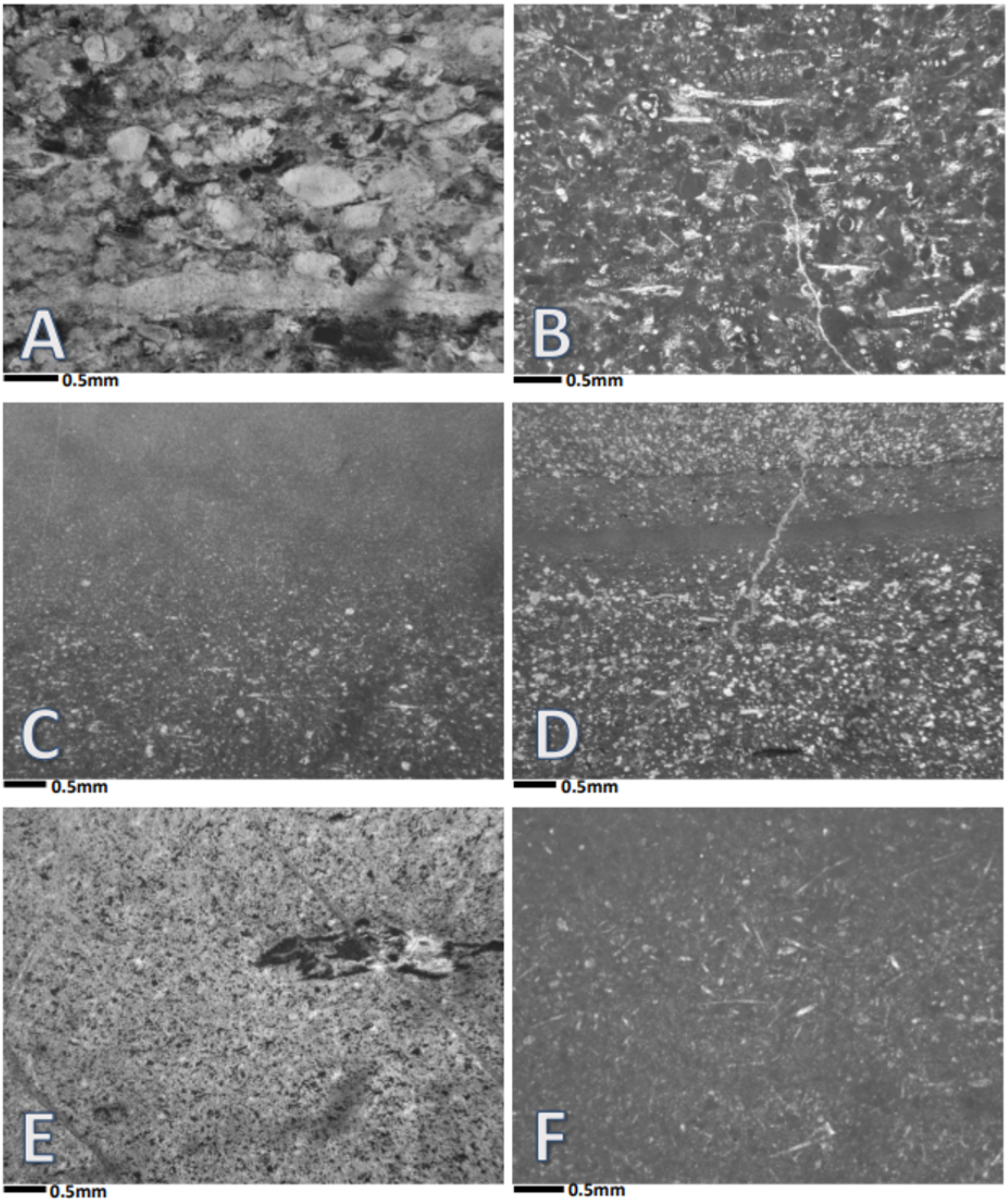

Figure 5: A) Grainstone-packstone, coarse-grained and non-laminated with silicified foraminifers, ostracods, miliolids (sample: PS2). **B)** Slightly silicized packstone with foraminifers and isooriented sponge spicules, textulariids, *Pseudonummoloculina* sp., valvulinids, *Cuneolina pavonia*, *Akaya minuta*, fragments of molluscs (sample: PS8). **C)** Micro-laminated packstone-wackestone with sponge spicules, textulariids, valvulinids, *Glomospira* sp., *Thaumatoporella* sp., (sample: SPIC2). **D)** Micro-laminated, fine grained packstone, with sponge spicules and foraminifers as valvulinids, miliolids*;* mollusc fragments (sample: PS4). **E)** Not laminated and highly silicized grainstone. Unrecognizable microfauna (sample: PS12). **F)** Not laminated and silicized wackestone with abundant sponge spicules (sample: PS12a).

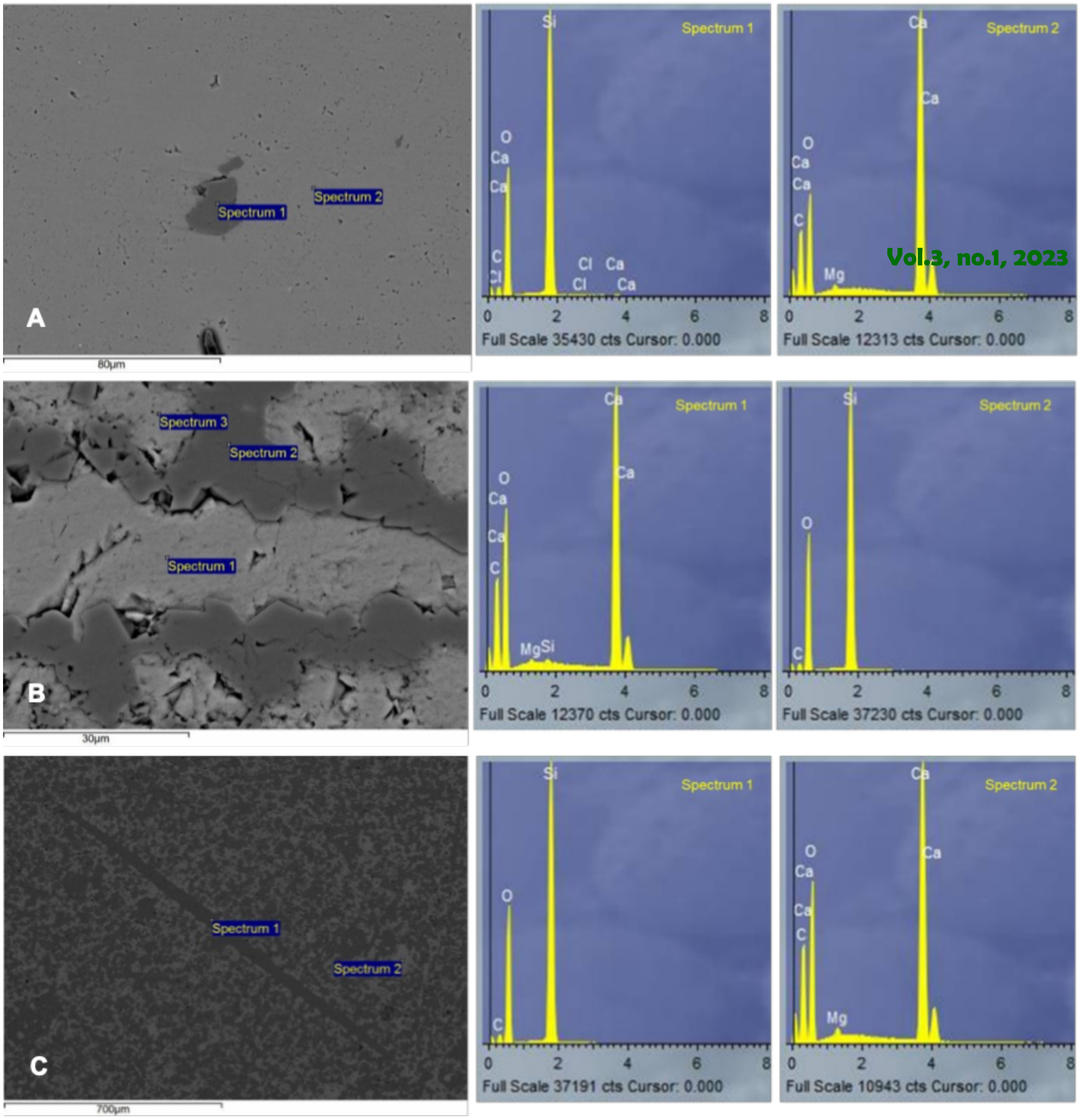

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Figure 6: Backscattered SEM images and relative chemical points analyses of matrix and sponge spicula. **A)** Sample Spic1. **B)** Sample Spic2. **C)** Sample P5.

Assuming the described conditions, abundant presence of spicules of siliceous sponges in the Ichthyolitic Limestones of Pietraroja, testifying the wide diffusion of porifera colonies in the area, living in shallow waters, probably on both incoherent and hardened substrates (early diagenesis, clasts) in areas overlooking the lagoon or in the lagoon itself, but where there was a better water circulation (sponge colonies are found on different substrates, both incoherent and hard, from the Cambrian up to the present. They can consolidate incoherent seabeds and are considered "ecosystem engineers". See for example: Aurell & Badenas, 2015; Tomas *et al*., 2019; Van Soest *et al*., 2012; Mercurio *et al*., 2006; Giraldes *et al*., 2020; Clarke, 1920; Renard *et al*., 2013). These organisms could greatly benefit from contributions of primary silica (carbonate weathering and "Orbitolina level"), obtaining material for the

Table 2: Values of major oxides (wt%, EDS, recalculated) of matrix and "spicule" in Spic1, Spic2 and P5 Samples. (1 and 2 are referred to point analysis in Fig.5).

Spic1	SiO_2	MgO	CaO	Tot.
1	99.55	-	0.45	100.00
2	-	0.59	55.41	56.00
Spic2	**SiO_2**	**MgO**	**CaO**	**Tot.**
1	-	0.41	55.59	56.00
2	99.74	-	0.26	100.00
P5	**SiO_2**	**MgO**	**CaO**	**Tot.**
1	100.00	-	-	100.00
2	-	0.92	55.08	56.00

construction of siliceous skeletons and proliferating. Sponge spicules, derived from the continuous process of death and renewal of the colonies, can then mix with the sediments of the lagoon and, being constituted by Opal A, they were easily solubilized in such specifical environmental conditions.

Based on the paleoenvironmental framework described above, formation of the different types of cherts in the Ichthyolitic Limestones of Pietraroja seems to be well explained by applying the genetic model proposed by Knauth (1979). This provides a mixing zone between fresh meteoric and salty sea water, which leads to supersaturated solutions in silica (dissolution of spicules) and subsequently, its reprecipitation in colloidal form, originating chert beds and nodules and replacing calcite in microfauna.

In the case study, due to the fine grain of the sediments, the mixing zone had a very limited thickness, also involving the lower part of the lagoon, and precipitating silica, thus forming extensive chert beds (Fig. 8).

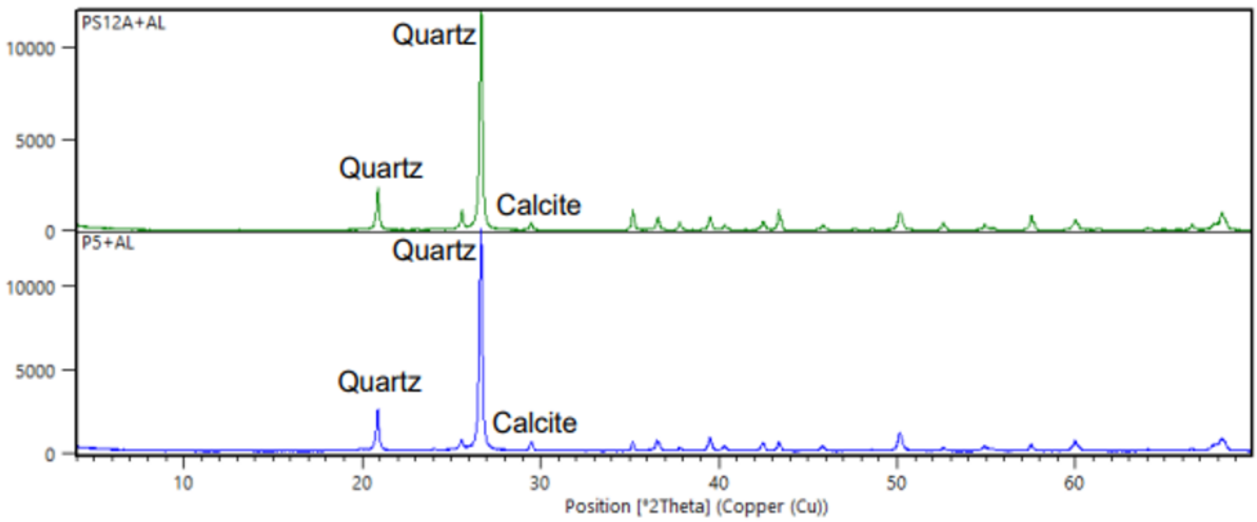

Figure 7: XRPD patterns of P12A and P5 samples.

In marginal, and more unstable areas of the lagoon, siliceous colloidal gel tended to form nodules, since the silica-supersaturated waters could not stratify here, conversely to what happens in the calm environment of the lower part of the lagoon. Nodules also prevail in the highest portion of Ichthyolitic Limestones formation, since the lagoon basin tends to be filled with coarser sediments, thus establishing itself in its "last stages of life".

In conclusion, chert in the Ichthyolitic Limestone formation of Pietraroja was formed due to:

- a shallow lagoon setting;
- presence of primary sources of silica, consisting of pyroclastic deposits affected by weathering on the emerged carbonate platform;
- transport of silica-rich fluids that favoured the development of silicosponge colonies in the lagoon or in its marine surrounding areas;
- sponge-derived biogenic silica present in the sediments (spicules). It was brought into solution by rain and freshwater and, in the mixing zone, at the edge of the lagoon, it was re-precipitated as colloidal siliceous gel, according to the model of Knauth (1979), forming chert nodules in the steeper, and unstable, marginal areas of the lagoon. In the distal areas, wide chert layers can stratify on the flat and calm basin bottom, with silica-saturated waters.

The proposed mechanism for the formation of chert in the Ichthyolitic Limestones of Pietraroja, is a further indication of their deposition into a shallow lagoon environment, close to emerged lands.

Author contributions

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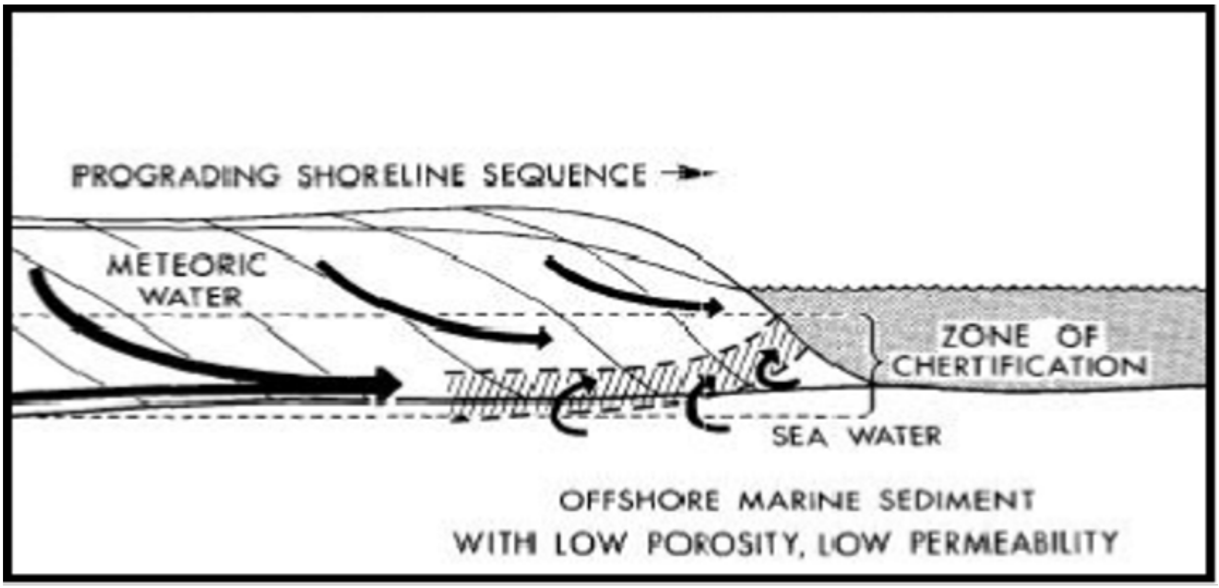

Figure 8: Scheme of the silicification model (from Knauth 1979).

Writing – Original and Final Draft Preparation: S. Bravi, M. Lo Russo, C. Rispoli, P. Cappelletti.

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First data on the presence of *Lutra lutra* in Bosco Incoronata Natural Regional Park (Apulia, South Italy)

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Abstract

The Eurasian otter, *Lutra lutra*, is a protected species in Italy since 1971 and it is threatened mainly by fragmentation and loss of habitat. Otter's conservation plans started in 2010 and areal extension was found to consist of two small and disjointed nuclei. Recent research confirmed the expansion of occupied areas, especially in Abruzzo and along Apulian River basins. We studied the otters in the Bosco Incoronata Natural Regional Park (in the north of Apulia region) by means of line transects and camera-traps techniques. Our results confirm the persisting presence of individuals. On this evidence, further studies are recommended in the entire river basin and whole Tavoliere area to better define the *status* of the species.

Keywords: *Lutra lutra*, presence, range expansion, Parco Naturale Regionale Bosco Incoronata, Apulia.

Riassunto

In Italia, la Lontra euroasiatica (*Lutra lutra*) è una specie protetta fin dal 1971 e la minaccia principale è costituita dalla frammentazione e distruzione dell'habitat. I piani di conservazione relativi alla specie avviati dal 2010, hanno restituito risultati incoraggianti circa l'estensione dell'areale, che inizialmente risultava composto da due nuclei piccoli e isolati. Recenti ricerche hanno confermato l'espansione delle aree occupate, specialmente nei bacini abruzzesi e pugliesi e in questo contesto si inserisce il presente lavoro da cui si è evinta la presenza stabile della specie nel Parco Naturale Regionale Bosco Incoronata (nord-Puglia). Quest'evidenza incoraggia la prosecuzione delle ricerche nell'intero bacino fluviale e in tutta l'area del Tavoliere al fine di incrementare le conoscenze circa lo *status* della specie.

Parole chiave: *Lutra lutra*, areale, Parco Naturale Regionale Bosco Incoronata, Puglia

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Introduction

During the XX century, the Eurasian otter, *Lutra lutra*, was one of the most threatened species in Italy, mainly because of hunting and loss of habitat caused by riverbanks modification and water pollution. This condition reached its peak during the '70s - '80s (Prigioni et al., 2005c, 2007; Kalby et al., 2003; Reggiani & Loy 2006) and led to the total species disappearance in the Northern Italy while causing the severe decline and range reduction in the rest of the Peninsula (Macdonald & Mason 1983b; Cassola 1986). Since the '90s, signs of otter's presence were reported in central and southern Italy. In 2011, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) described two small and isolated *nuclei*: the "*meridionale nucleus*", which covers Calabria, Basilicata, Apulia, and Campania regions, and the "*molisano nucleus*", which covers Molise and Abruzzo (Extent of Occurrence, sensu IUCN 2001). At present, recent evidence demonstrated the presence of *Lutra lutra* in northern Italy (Loy et al., 2015; Lapini et al., 2020), and the species seems to expand its areal in the southern parts of the peninsula (Marcelli & Fusillo 2009; Prigioni et al., 2005a, 2007; Reggiani & Loy 2006; Bolinesi et al., 2019; Buglione et al., 2020a).

Lutra lutra is an indicator species of wetlands and freshwaters ecosystems (Lunnon & Reynolds 1991). Its presence depends on environmental integrity, which is generally affected by anthropic activities and habitat fragmentation and modification. The otter's *status* can be described through monitoring plans and the development of specific management guidelines.

Since 2007, an increased number of reports on dead individuals and findings of faecal samples in Apulia (southern Italy) indicated the presence of otters in this region (Buglione et al., 2020a). This especially referred to the Tavoliere area (north of Apulia) (Marrese et al., 2014; Giovacchini et al., 2018); signs of presence were discovered in Fortore, Candelaro, Carapelle and Ofanto rivers, while several road-killed individuals were found in Manfredonian (Fig.1A) and Ionian Gulf. Furthermore, in 2020, an camera-trap caught a one-snap image of an individual in Bosco Incoronata Natural Regional Park (Parco Naturale Regionale Bosco Incoronata or PNRBI; Gaudiano unpublished) (Fig. 1B).

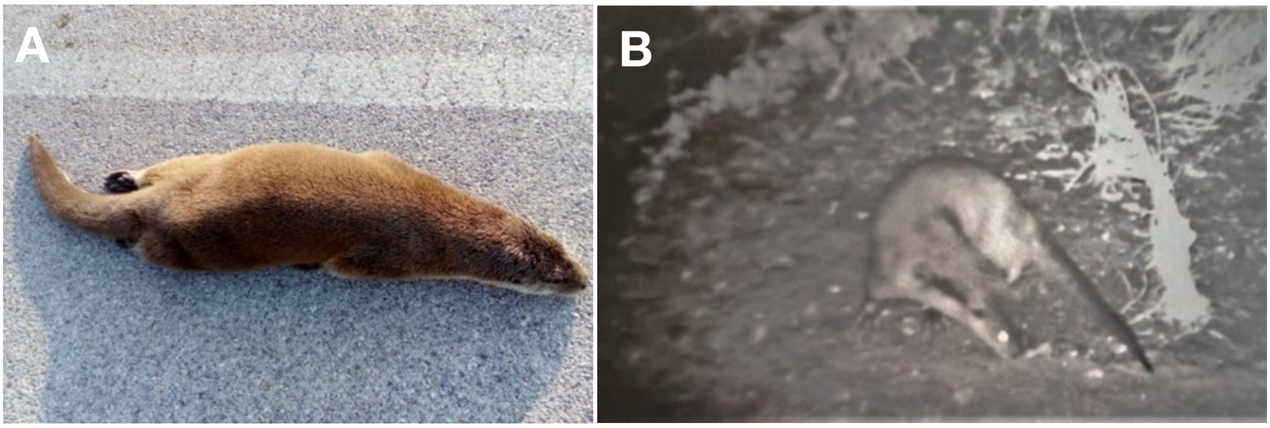

Figure 1: A) Road-killed male otter in Manfredonia territory (V. Talamo unpublished, 2018). **B)** First presence of otter in PNRBI (Gaudiano 2020, *pers. obs.*).

The present study aimed to confirm the presence of *Lutra lutra* in PNRBI and characterize its *status* to define whether the species is occasionally or permanently present in the investigated area as this park plays an important role in the geographical disposition of the species range expansion. PNRBI is part of the Community Importance Site (SIC) IT9110032 "Valle del Cervaro - Bosco dell'Incoronata", which extends from the Apennine area to Incoronata village (Tavoliere area, territory of Foggia), and conservations plans are consistent with the protected area's goals.

PNRBI is a little patch of humid lowland forest along the Cervaro river and it is characterized by gallery forest and dense riparian vegetation surrounded by intensive farming fields, human activities, and paved roads (Fig. 2). The Tavoliere Plain is almost completely cultivated with cereals and partially with vegetables, vineyards, and olive tree groves. An extensive road and rail network crosses the entire area. Furthermore, the third largest town of the Apulia region, Foggia, is only 12 km far from PNRBI. The Park is located between two otter's *nuclei*, and between two major Apulian protected areas (Alta Murgia National Park and Gargano National Park) and Subappennino area. Being crossed by the Cervaro river, it represents a connecting zone and a hotspot where otters from both *nuclei* can find shelters, food, and potential territory for reproduction.

The Cervaro river is characterized by a variable water flow among seasons: during winter it floods where the riverbanks are lower and undefined. During summer, it dries almost completely, except for some ponds, and the riverbanks are more than three meters high (Fig. 3). The vegetation close to the water stream is typically the Mediterranean, with dense and tangled shrubs hindering the access to the riverbed.

Methods

The work was conducted from May to November 2021 and the entire Park area along the river course (5,6 km length) was investigated using -when necessary- a little boat, adjusting PACLO (Piano d'Azione Nazionale per la Conservazione della Lontra, or otter's national action plan) guidelines based on the standard method (Reuther et al., 2000) to the PNRBI layout.

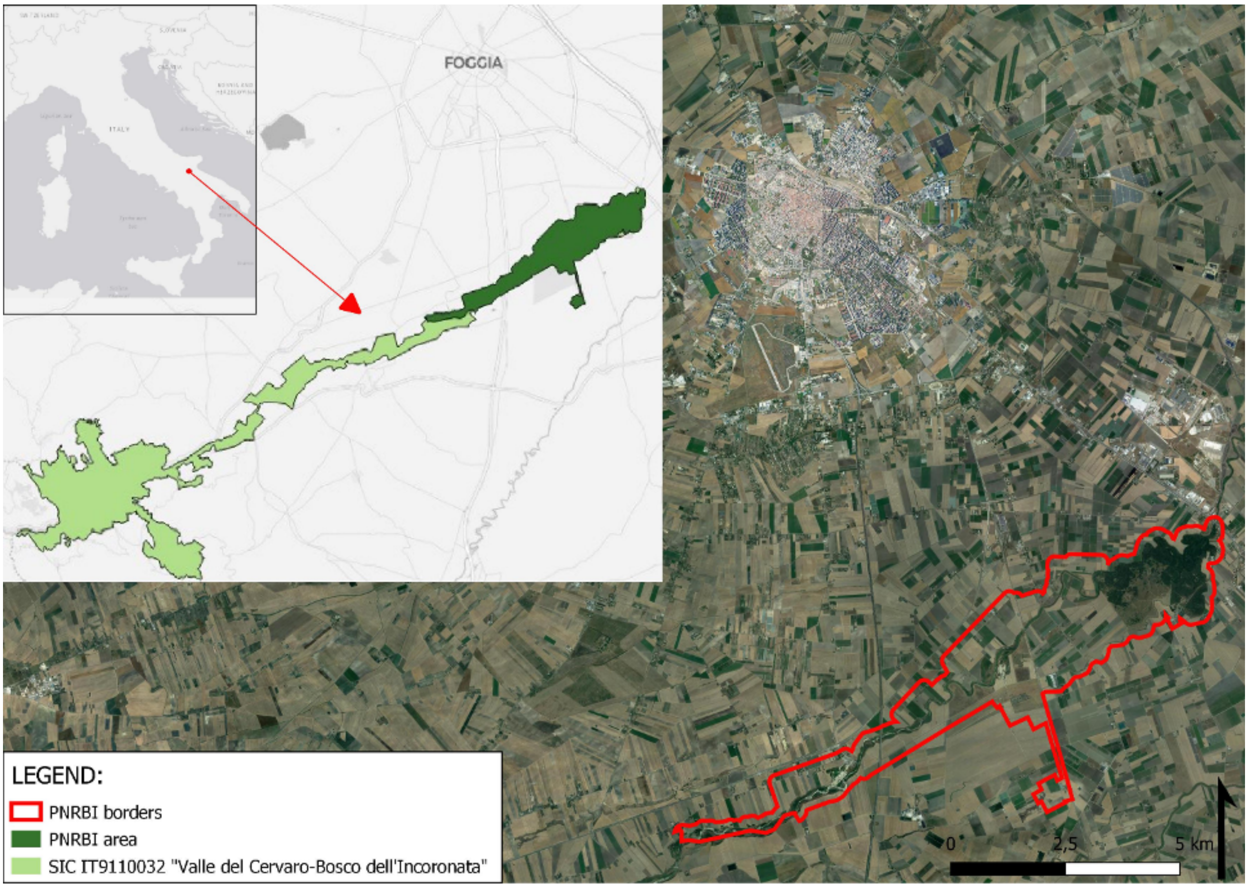

Figure 2: SIC IT9110032 "Valle del Cervaro-Bosco dell'Incoronata" in light green; Bosco Incoronata Natural Regional Park (PNRBI) in dark green; Bosco Incoronata Natural Regional Park (PNRBI) borders in red.

The sampling methods involved line transects and camera-traps techniques. Monitoring was divided into two phases: the first -from May to August- consisted of the analysis of territory, while the second -from August to November- included sampling in line transects. Camera-trap activity was conducted in both phases.

The river course was divided into five line transects from approximately 1 km length each and they were investigated twice walking through the riverbed. The check was carried out in five fieldwork days to collect faecal samples, footprints, tracks, and other signs of presence. Faecal samples were gathered for further diet analyses, and was associated with an alphanumeric code. In order to outline which environmental variables influence the choice of the marking site by otters, six parameters have been considered, such as riparian vegetation cover, water flow speed, substratum, bank slope, depth of the river, rocky outcrops. Each one has been recorder within a 5 meters radius from the spraint. All the information and the related GPS positions have been recorded in a specific field datasheet.

The camera-trap activity was conducted using 5 camera-trap equipped with PIR and LED sensors, placed near to the otter's most probable passageways, set on working time from 18:00 to 8:00 of the following day, with 20 sec. length video-mode.

Figure 3: Cervaro riverbed during summer. The river dries up most of the way, except for few remaining ponds.

All data were collected in a specific datasheet, and two databases have been created (camera-trap DB and faecal sample DB).

Results

Fifty-one spraints have been collected in three months, 14 of which were found fresh (laid within a week) generally on rocky outcrops. They were found along the entire river course, but the most in the middle part of it, where vegetation cover is abundant and the riverbank is unreachable by people, thus the anthropic disturb is very low.

The predominant environment parameters are shrubby and arboreal vegetation, absent or standing waterflow on a rocky substratum, gentle bank slope and shallow depth of the river with a medium grade of rocky outcrops (Fig. 4).

The sprainting activity abundance has been calculated using KAI (Kilometric Abundance Index) (Vincent et al., 1991; Buckland et al., 1993) and it corresponds to 0.91 spraint/100 m. The result is consistent with previous studies carried out by Prigioni in Pollino National Park (Prigioni et al., 2005a), who described 3.2 spraint/100 m (32 spraint/km) in 32 stretches (mean length 673 m).

Preliminary spraint content analyses (Fig. 5) detected a major presence of amphibians and fish bones and scales and a minor presence of invertebrates, such as the crustacean *Potamon fluviatile*.

Regarding camera-trap activity, three videos confirmed the presence of the species. In particular, the videos were recorded on 7

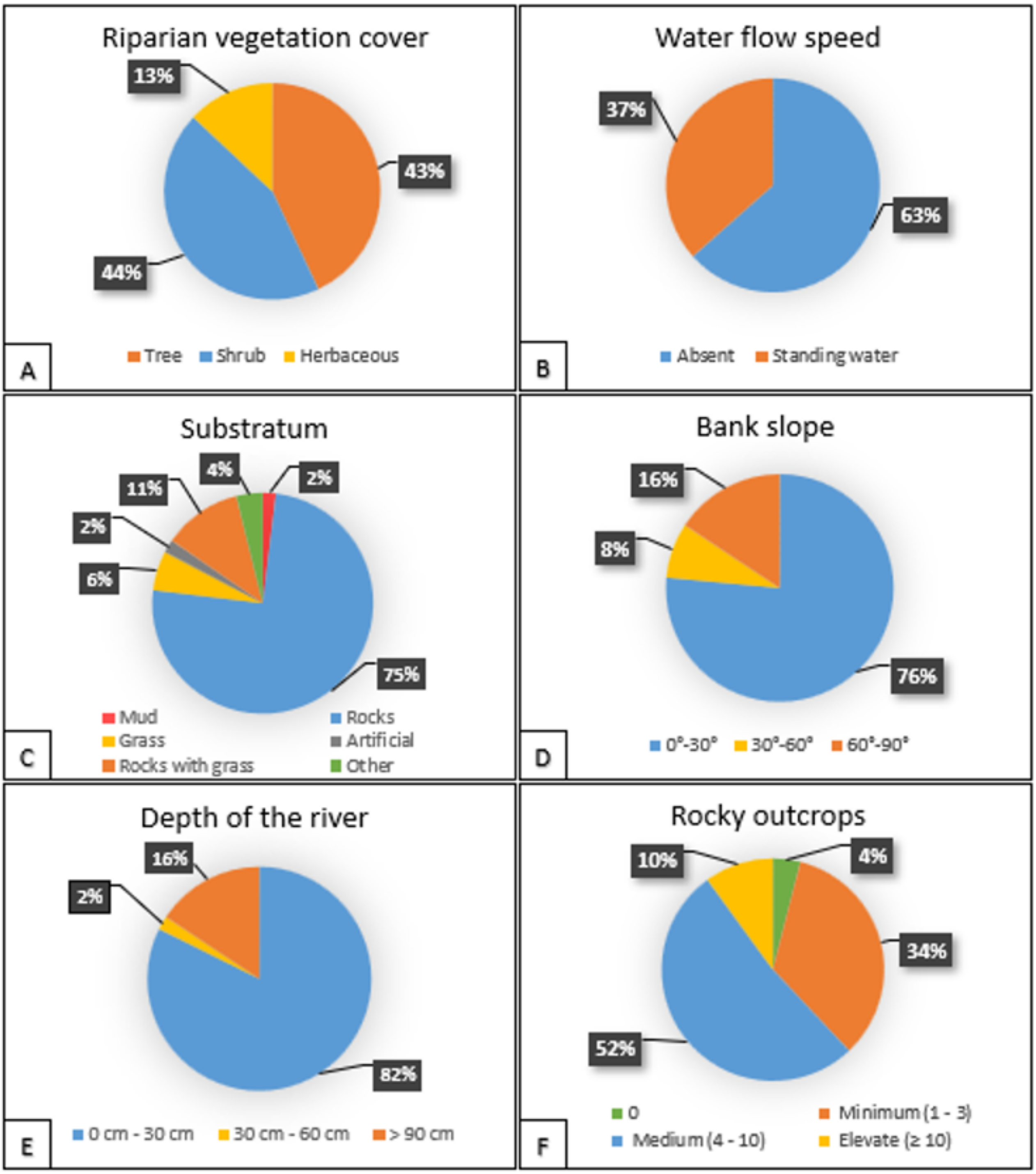

Figure 4: Results of environmental parameters analyses. **A)** Riparian vegetation cover classified by Tree, Shrub or Herbaceous. **B)** Water flow speed classified by Absent or Standing water. **C)** Substratum classified by Mud, Grass, Rocks with grass, Rocks, Artificial, Other; **D)** Bank slope classified by 0°-30°, 30°-60°, 60°-90°. **E)** Depth of the river classified by 0-30 cm, 30-60 cm, >90 cm. **F)** Rocky outcrops classified by 0, Medium (4-10), Minimum (1-3), Elevate (≥ 10).

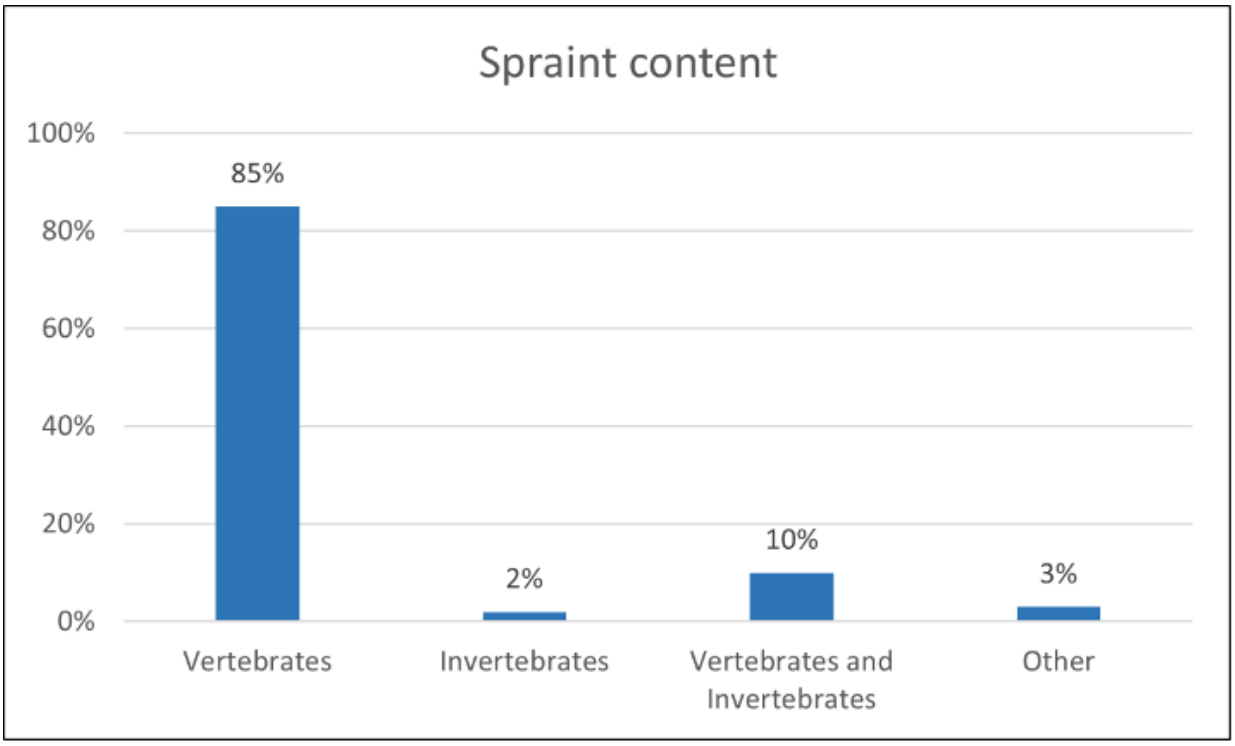

Figure 5: Percent contribution of the remains of different groups in spraint content, such as Vertebrates (85%), Invertebrates (2%), Vertebrates and Invertebrates (10%) and Others (3%).

October 2021 from the same camera-trap, at a two-hour interval. The first and the second videos are subsequent and captured two individuals moving together toward the camera; the third shows an otter while hunting in the underlying pond (Fig. 6), where 10-15 cm long fish were found.

Discussion

Our survey confirmed the presence of *Lutra lutra* in PNRBI and suggests that the species is settled in the area with a minimum of two individuals.

The analyses of the environmental data outline an ecological framework compatible with the habitat' species: dense riparian vegetation (Adrian 1985; Ruiz-Olmo & Delibes 1998; Prenda et al., 2001) where otters can find shelter, small or medium sized watercourse with rocky substratum and gentle bank slope (Chanin 2003) where to hunt. During summer, few remaining ponds promote a greater concentration of fishes, crustaceans and amphibians and are used by otters for feeding (Remonti et al., 2008; Fusillo 2006) and Cervaro river in his PNRBI section is characterized by absence of waterflow and numerous ponds. This survey confirmed that the otter's diet is flexible and dependent on prey availability (Prigioni et al., 1991a, b, 2005b; Cannetiello et al., 2005; Fusillo 2006; Buglione et al., 2020b). When possible, fish is the most important trophic source, followed by amphibians and crustaceans, although further studies on the diet composition of this population are needed.

KAI shows a high level of presence of the species in the PNRBI area and fresh spraints collected in the entire sampling time suggest otters frequent the area regularly. Since isn't

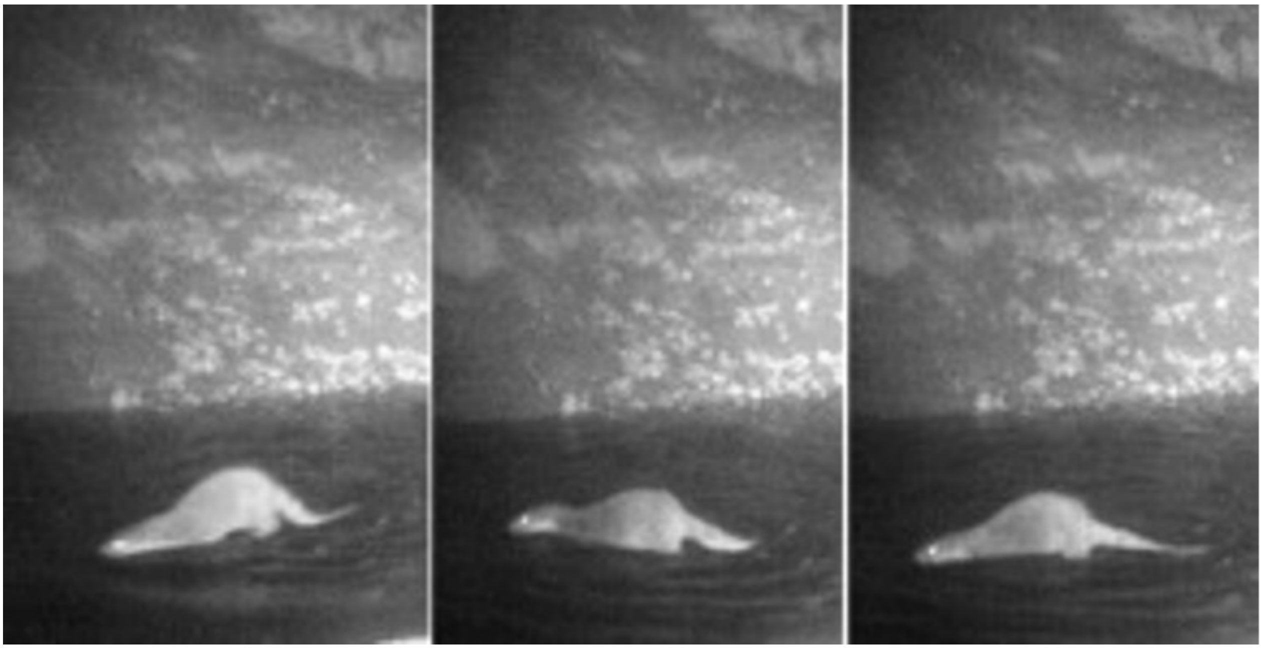

Figure 6: Frames of a video in which an individual is shot while hunting in a pond in PNRBI. The video was recorded during the survey's activity on 7 October 2021 at 22:33.

possible to correlate the sprainting activity abundance to the number of individuals within an area (Panzacchi et al., 2010), this latter information is available only by camera-trap activity, from which is possible to confirm a minimum of two adult individuals.

PNRBI, due to its position, represents a connecting zone of the two *nuclei* and their merge represents an effective areal expansion and increase of genetic variability. This contributes to the improvement of the Italian otter population's *status*.

The study area comprised a small portion of the entire Cervaro area, and further research should cover the entire river basin and Tavoliere area to obtain comprehensive knowledge on the status of the otter population in the north Apulia.

Confirmation of otter's presence in PNRBI paves the way to further studies on this species, its biology and ecology, but also on general environmental *status*. It is of great importance to safeguard this species in order to preserve the total biodiversity of PNRBI. Indeed, the otter is also considered an "umbrella" species (Bifolchi & Lodé 2005), and its protection helps to protect the entire wetland and freshwater ecosystems. This seems especially important in the PNRBI area, which is constantly threatened by nearby villages, human activities, and intensive agriculture. Its presence in the proximity of a large city, such as Foggia, should be of great concern in the city's development from a green and sustainable perspective, demonstrating that human activities and natural environments are connected and mutually supported.

Author contributions

Planned the sampling: L. Guadiano.

Performed field work and data entry: L. Guadiano and A. Cascella.

Ran the analysis and wrote the first draft: P. Lerario and A. Cascella.

All the authors have read the draft and have accepted responsibility for this manuscript and approved submission.

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Aerobiology of Algae and Cyanobacteria

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Abstract

Algae and cyanobacteria are considered the major groups of primary producers on this planet. Many food webs begin with these microorganisms, making their presence as primary producers vital for creating a perfect ecosystem in the air and sustaining their dependents. These microbes in the air can be both harmful and useful due to their unique metabolic pathways (photosynthesis) and metabolites (toxins). Additionally, certain activities can have global climate impacts (such as ice nucleation). Atmospheric microbiology has been an understudied area of biodiversity. This review complies a few studies on the diversity and distribution of atmospheric primary producers such as algae and cyanobacteria.

Keywords: Atmosphere, troposphere, stratosphere, microalgae, cyanobacteria

Riassunto

Le alghe e i cianobatteri sono considerati i principali gruppi di produttori primari del pianeta. Molte reti alimentari iniziano con questi microrganismi e la loro presenza risulta vitale per creare un ecosistema anche nell'aria e per sostenere gli altri organismi che dipendono da loro. I microrganismi fototrofi che vivono nell'aria possono essere sia dannosi che utili, grazie alle loro vie metaboliche peculiari (fotosintesi) e ai loro metaboliti (tossine). Inoltre, alcune attività metaboliche connesse alla loro presenza possono avere un impatto sul clima globale (come la nucleazione del ghiaccio). La microbiologia atmosferica è un settore poco studiato della biodiversità microbica; questa review raccoglie alcuni studi sulla diversità dei produttori primari atmosferici e sulla loro distribuzione nei vari strati dell'atmosfera.

Parole chiave: Atmosfera, troposfera, stratosfera, microalghe, cianobatteri.

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Introduction

An Atmosphere is a layer of gases that envelop a planet and are in place by the gravity of the planetary body. The atmosphere of Earth is composed of nitrogen (78%), oxygen (21%), argon (0.9%), carbon dioxide (0.04%), and trace gases. the atmospheric nitrogen can be converted into N-reduced compounds by natural processes, such as lightning or biological nitrogen fixation by bacteria (Mus et al., 2016). These processes produce molecules needful for nucleotide and amino acid synthesis. Additionally, plants, algae, and cyanobacteria use carbon dioxide for photosynthesis. The layered composition of the atmosphere minimizes the harmful effects of sunlight, ultraviolet radiation, solar wind, and cosmic rays to protect organisms from genetic damage. The current composition of the atmosphere of the Earth is the product of billions of years of biochemical modification of the paleo atmosphere by living organisms.

The lowest layer of the atmosphere is called troposphere, extending from the planetary surface to the bottom of the stratosphere. The troposphere contains 75 % of the atmosphere mass and is the layer wherein the weather occurs. The height of the troposphere varies between 17 km at the equator and 7.0 km at the poles. The stratosphere extends from the top of the troposphere to the bottom of the mesosphere, representing layer between 15km and 35km of altitude that absorbs most of the ultraviolet radiation that Earth receives from the Sun.

The mesosphere ranges from 50 km to 85 km and is the layer wherein most meteors are incinerated before reaching the surface. From an altitude of 85 km to the base of the exosphere, at 690 km, there is another layer named thermosphere which contains the ionosphere, where solar radiation ionizes the atmosphere. The ionosphere's density is greater at short distances from the planetary surface in the daytime and decreases as the ionosphere rises at night, allowing a greater range of radio frequencies to travel greater distances. Moreover, the Karman line at 100 km is in the thermosphere, which is considered as a theoretical boundary between outer space and the Earth's atmosphere. The exosphere begins at 690 – 1,000 km from the surface and extends to roughly 10,000 km, where it interacts with the magnetosphere of Earth.

Researchers in recent decades have studied the diffusion of microbial cells in the atmosphere. Seetharam et al. (2015, 2016) have found fungal spores belonging to 14 different families on spiderwebs, which are located in the troposphere, whereas the presence of microorganisms in clouds has also been reported (Woo et al., 2018). The evidence of the presence of microorganisms in the upper layers of the atmosphere was found for the first time by using meteorological rockets. Imshenetsky's team found fungal spores as well as bacteria in the mesosphere, at an altitude ranging from 48 - 77 km (Imshenetsky et al., 1978). More recently, some studies reported the presence of bacteria in the stratosphere Shivaji et al. (2006, 2009) (DasSarma et al., 2020) and the viruses (Wickramasinghe et al., 2020). Moreover, bacterial DNA has been even found in the ionosphere, on the illuminator of the international space station (Grebennikova et al., 2018). According to Tesson et al. (2016) Chlorophyta, Bacillariophyta, and Ochrophyta are the most represented taxa, occurring throughout the world, in the lower layers of the atmosphere. Other reviews have described the importance of aerosol microalgae and cyanobacteria and discussed the possible impact of their diffusion on human health and the environment (Tesson et al., 2016; Tesson & Šantl-Temkiv, 2018; Wisniewska et al., 2019).

This brief review gathers the research articles showing the presence of phototrophic microorganisms in the atmosphere, with a special focus on the cyanobacteria and algae at different layers of the atmosphere.

Methods

Air Sampling

Sampling algae from the air is done through passive and active air flow methods. The active air sampling methods use the electric or mechanical pumps to draw the air into/onto the collection device/medium with known rate of airflow. While the passive air sampling methods depends on the natural air movement.

The passive sampling and preliminary investigations are done by exposing Petri dishes containing sterile, solidified, and inorganic nutrient medium known as Bold's Basal Medium , (BBM) or modified Bold 3 N media (B3N) , directly to air for some time (Carson & Brown 1976). By incubating them for some period, this inorganic medium does not encourage the luxurious growth of heterotrophic contaminants (fungi and bacteria) but instead allows only the growth of algae (Sathish et al., 2020; Wiśniewska et al. 2020; Chiu et al., 2020).

The active sampling device, such as the rotarod sampler (Marshall & Chalmers, 1997) relies on the movement of air generated by the moving arms of the sampler. Both arms of the sampler cleaned with acetone, and sterile double adhesive tape is stuck to the arms just before the sampling (Comtois et al., 1999). Rotarod samplers are exposed to air for a short duration (30 min) to minimize the deposition of any toxic substances on the adhesive tapes. The impacted tapes are removed from the arms aseptically, cut into small pieces, and placed face down on Petri plates containing solid BBM to follow the culture-dependent identification method (Sharma et al., 2006; Groot et al., 2021). An impaction culture plate sampler (air IDEAL3P, bioMerieux, France) has also used, which can collect 500 liters of air with a 100 ml/min for 5 min. Air is aspirated in the sampler through a grid perforated with a pattern of 286 calibrated holes. The airstream containing the microbial particles is directed onto the surface of Bold's Basal Medium (BBM) agar (Carson & Brown, 1976) in a sterile petri dish (90mm in diameter) attached to the air sampler (Chu et al., 2013). In the last decades, many other air samplers with similar principles have been developed and used to collect microbes from the air. (Genitsaris et al., 2011; Chu et al., 2013; DeLeon-Rodriguez et al., 2013; Smith, 2018; Aalismail et al., 2021; Wiśniewska et al., 2022).

Identification of algae and cyanobacteria

Identification of airborne algae and cyanobacteria can be done using culture-dependent methods or culture-independent methods. Culture-independent methods are used to identify microbes without cultivating them, while culture-dependent methods require the microbe to be grown after sampling.

Culture-Dependent Method. During the sampling period, airborne particles collected directly onto agar-solidified plates or into a conical flask containing sterile distilled water using passive or active air sampling methods. For the air-drawn plate, we should wait for the growth of the microbe and use microscopy to identify microbes. For the water samples impacted with direct air by the sampler, we can directly add Lugol and can be taken for microscopic analysis. (Carson & Brown, 1976; Sharma et al., 2006; Genitsaris et al., 2011; Chu et al., 2013; Sathish et al., 2020; Wiśniewska et al., 2020, 2022; Chiu et al., 2020).

Culture-Independent Method Air samplers direct the air to specified filters to which the microbes are attached. After recovering the filter, we can extract the DNA and use metagenomic sequencing or amplicon-based sequencing to identify the taxa in the sample (Smith et al., 2018; Dillon et al., 2021; Aalismail et al., 2021; Groot et al., 2021; Drautz-Moses et al., 2022).

An overview of studies reporting Cyanobacteria and algae in the Atmosphere

As mentioned before, the troposphere contains 75 % of the atmosphere's mass. Many studies show the presence of airborne algae and cyanobacteria in the troposphere, either in filaments or in spore forms. The first note of algal presence in the atmosphere dated back to the 1830 Gregory, P. H, (1961). But scientists haven't emphasized the abundance and variety of airborne algae due to the lack of prolonged cultivation after exposure to air. Taxonomically, airborne microalgae belong either to the prokaryote's cyanobacteria (also known as blue-green algae) or some unicellular microeukaryotes. Also, moustaka's team stated that 353 morphological taxa had been observed (Moustaka-Gouni, 2011).

The investigations by VanOvereem (Overeem, 1937) represented their pioneering efforts to recover and cultivate airborne algae. They successfully collected 24 air samples from an airplane at various altitudes over the Netherlands on six different occasions and recovered nine different algal isolates. Among the recovered isolates, *Chlorococcum* appeared most frequently. Samples from an altitude of 500 m provided the most abundant algal flora. Further collections at ground level, using an air pump and rainwater samples, revealed at least eight different species, *Chlorococcum* again being the most abundant. These collection methods also obtained a Myxomycete plasmodium, moss protonemata, and fern prothallia. They also mentioned that the algal content of dust could be extremely high, and the count has revealed no less than 3000 algae per cubic meter. Counts of this nature indicate that algae may exist in sufficient quantity in the air to be a possible cause of inhalant allergy (Brown et al., 1964).

During the summer of 1971 and autumn of 1973, a transect was set up on the island of Hawaii from the coastal city of Hilo up to 6500 ft on the slopes of Mauna Loa. Sterile Petri dishes of agarized BBM were exposed at different altitudes, between 1000 to 5000 ft intervals, for 1 minute each from an automobile traveling at 35 miles per hour. The Plates were incubated for one month on a continuous light cycle of approximately 3500 lux and 19°C, and members belonging to the genera *Chlorella, Chlorococcum, Oocystis*., *Protococcus*. *Hormidium, Calothrix, Oscillatoria, Symploca, Lyngbya, Entiphysalis, Synechocystis, and Monallantus* were observed (Carson & Brown, 1976).

Samples collected 1 meter above the ground between 14 December 1992 and 28 January 1994 at three sites on Signy Island, Antarctica, showed the presence of red cysts (aplanospores), *Chlamydomonas nivalis, Chlorosphaera antarctica*, cyanobacterial filaments, and chlorophyte filaments, probably *Zygnema* spp. (Marshall & Chalmers, 1997).

At the beginning of this century, Sharma et al. (2006) reported that cyanobacteria were the abundant photoautotroph in Varanasi, India, during summer, while winter favors green algae. The presence of diatoms was almost uniform throughout the year. They observed 34 different aero algae genera including *Microcoleus* sp. and *Spirulina* sp. at 2.5 meters in height. They also mentioned the presence of algal particles in the air depending upon the abundance and dynamics of algal source and their release and dispersal in the atmosphere.

Another study is in the city of Thessaloniki, Greece, a densely populated and industrialized city reported to have high ambient concentrations of airborne particles that contain elements such as NaCl, K_2O, NiO, Cr_2O_3, MnO_2, Fe_2O_3, PbO, Cu_2O, ZnO, Sb_4O_6, CdO, and V_2O_5, As_2O_5 and Co_3O_4 at levels greater than the proposed. During the period October 2007 to April 2008, Maria Moustaka-Gouni and her team evaluated the diversity of aero algae in the atmosphere. Twenty-nine species of airborne micro-eukaryotes were identified. Airborne organisms of eight taxa were also detected in the nearby aquatic systems. The algae *Haematococcus lacustris,* a *Chlorella*-like taxon, and *Scenedesmus cf. obliquus,* the heterotrophic nanoflagellates (HNF) *Bodo* sp., *Cafeteria minuta,* and *Rynchomonas nasuta,* and the ciliate *Pattersoniella vitiphila* were present in all three seasons. *Grammatophora* sp., *Nitzschia* sp., *Spumella* sp., *Chlamydomonas* spp., *Chlorosarcinopsis bastropiensis, Gloeotila sp., Lobosphaera tirolensis, Monoraphidium minutum, Mougeotia* sp., *Stichococcus* sp., *Trebouxia impressa, Zygnema* sp. are also found. They also studied the food webs in all seasons. They stated that in all seasons, the abundance ratio of autotrophs to heterotrophs was <1 in the initial phase of the colonization (Week 1), indicating the dominance of heterotrophic microeukaryotes. The <1 ratio was maintained in autumn and winter for 4 weeks. However, in spring, the ratio changed from <1 to >15 through the 6 weeks, suggesting a transition from heterotroph to autotroph dominance (Genitsaris et al., 2011).

A study conducted in Malaysia aimed to investigate the occurrence and distribution of airborne algae and Cyanobacteria (AAC) in various environments, including indoor and outdoor areas of an office building in Kuala Lumpur, between February and October 2008. The results showed that AAC were present in almost every place, with Cyanobacteria, Chlorophyta, and Bacillariophyta being the most common taxa identified, some of them including *Chlamydomonas* sp., *Chlorococcum humicola* (Nägeli) Rabenhorst, *Chlorella ellipsoidea* Gerneck, *Scenedesmus bijugus* (Turp.) Lagerheim, *Phormidium retzii* (Agardh) Gomont, *Pseudanabaena* sp., and an unidentified filamentous cyanobacterium. The study also found that areas with heavy human movement had a high occurrence of AAC, with the highest occurrence (75%) recorded in the surrounding areas of the building and the lowest (45%) on the lower ground floor, an area exposed to the outdoor environment. In addition, some AACs were also detected in wall scraping and soil samples. The findings suggest that human movement is an important factor affecting the dispersal of AAC, which has implications for public health and indoor air quality (Chu et al., 2013).

To address airborne microorganisms in the upper troposphere and lower stratosphere, Smith and team collected samples from altitudes in the lower stratosphere (about 12 km) using flight-validated a novel Aircraft Bioaerosol Collector (ABC) which was installed on NASA's C-20A, and on four consecutive missions flown over the United States (US) from 30 October to 2 November 2017. Bioaerosols were captured on DNA-treated gelatinous filters inside a cascade air sampler, then analyzed with molecular and culture-based characterization which summarized the eight most abundant phyla detected in the study including Cyanobacteria (Smith et al., 2018).

In 2016 and 2017, Tesson and Šantl-Temkiv (2018) investigated for ice nucleation active (INA) compounds in Sweden. They isolated 81 strains of airborne microalgae from snow samples and determined their taxonomy by sequencing their ITS markers, 18S rRNA genes, or 23S rRNA genes. Out of the 81 isolated airborne strains, 56.8% were affiliated with Chlorophyta. The majority of these strains were represented by the class Trebouxiophyceae (40 out of 46 strains), while the rest were affiliated with Chlorophyceae (6 out of 46 strains) (Tesson & Šantl-Temkiv 2018).

We know that viable microalgae occur in the air. In 2013, to study whether microalgae can survive the stresses such as UV, desiccation, and freezing temperatures at high altitudes during a long-distance dispersal Chia–Sheng Chiu and team isolated four freshwater airborne green microalgae from Dongsha Atoll in South China Sea at two meters above the ground and identified as *Scenedesmus sp. DSA1, Coelastrella sp. DSA2, Coelastrella sp. DSA3* and *Desmodesmus sp.* Chlorophyta was found to be abundant in their samples (Chiu et al., 2020).

The Adriatic Sea region is one of the economically important water bodies due to tourism. To get information on the taxonomic composition of cyanobacteria and microalgae, The first sampling in this area conducted by K. A. Wiśniewska et al. (2020) between 11th and 15th June 2017. The study revealed the presence of cyanobacteria and microalgae, as well as the cyanobacterium *Snowella sp.* And the green alga *Tetrastrum sp.,* taxa that had not been previously documented in the atmosphere in any other studies. This sampling was carried out in the northern part of Italy (station 1), one in Croatia (station 2), and two in Montenegro (station 3 and station 4), which is 50 meters from the seashore and 1 meter above the ground.

To study the diversity of airborne algae in Bangalore, India, air samples were collected in four sites using the Petri plate exposure method and Benecks agar medium. A total of fifteen airborne algae belonging to twelve genera were identified, including members of Cyanobacteria, Chlorophyceae, and Bacillariophyceae. Cyanobacteria were dominant group with a total of seven genera identified: *Oscillatoria, Lyngbya, Microcoleus, Chroococcus, Nostoc, Anabaena, Hapalosiphon, Gloeocapsa,* and *Myxosarcina*. The Bacillariophycean members identified were *Cymbella and Nitzschia*, and the genus *Chlorella* represented the *Chlorophyceae*. Most of the species present in air samples were soil algae (Sathish et al., 2020).

Another study has investigated airborne eukaryotic communities (AEC) in dust of the highest dust flux place on the planet, the west coast of North Africa and Central Asia. Samples of atmospheric dust were collected from onshore and offshore locations of the Red Sea at ~7.5 meters over the sea level in Thuwal, Saudi Arabia, over 14 months (fall 2015–fall 2016). Algae from Rhodophyta, Chlorophyta, and Bacillariophyta were identified using Miseq sequencing. As usual, Chlorophyta was particularly abundant (0.97%) (Aalismail et al., 2021).

From March to June 2019, were collected 16 fan dust samples from 8 residences to investigate the intramural diversity of airborne algae in Pune, India over ten days. A total (of 108) aero-algal forms were recorded. Out of which 107 were Cyanophyta, and only one was *Chlorophyta*. *Anabaena, Scytonema, Calothrix,* and *Scenedesmus* were among the allergic aero-algal genera (Kamble & Pandkar 2021).

Recently, a study has been conducted to investigate the dispersal patterns of microbial taxa in the vertical air column. they collected samples from a meteorological tower in Germany and a flight at a height of 3500 meters, using dry electret filters and SASS3100 air samplers operated at an airflow rate of 300 L/min. Metagenomic Sequencing was performed to analyze the taxonomic composition of the airborne microbial communities, which showed differences in composition patterns based on the time of day and height above ground. the results revealed the presence of cyanobacteria and chloroflexi along with other prokaryotes and eukaryotes. The study also, showed that DNA amounts varied with time of day and height, highlighting the importance of investigating height-related changes in a time-specific manner. Specifically, the study observed a 400% difference in DNA abundance between day and night samples (Drautz-Moses et al., 2022).

Wiśniewska et al. (2022) recently have presented an innovative investigation of the washout efficiency of airborne cyanobacteria and microalgae in the Gulf of Gdańsk (southern Baltic Sea). Sampling was carried out in 2019 at 20 meters above sea level, which showed that the number of microalgae and cyanobacteria cells decreased by up to 87% after a rainfall event compared to before the rainfall event. Several harmful taxa, including

Chlorococcum sp., Oocystis sp., *Anabaena* sp., *Leptolyngbya* sp., *Nodularia* sp., *Pseudanabaena* sp., *Synechococcus* sp., *Synechocystis* sp., and *Gymnodinium* sp., were washed out by rain. This is crucial for human health as it reduces the chance of people inhaling these species and their toxic metabolic products. Figure 1 supports the washout of the biomass and aerosols due to rain and reveals the mountains in the background. The images were captured on two different dates in February 2023, before and after a rainfall event.

Sylvie Tesson and her team (2016) summarises the diversity of airborne microalgae. The review discusses their emission, transportation, deposition, and adaptation to atmospheric stress, as well as the consequences of their dispersal on health and the environment. It also includes a discussion of state-of-the-art techniques for detecting and modelling airborne microalga dispersal. Additionally, Hallmann (2015) and Tesson et al. (2016) investigated the algal colonization on different materials (building

Figure 1: Chiang Mai, Thailand. Top: photo taken on 15/02/2023. Bottom: photo taken on 17/02/2023, after a rainfall.

walls, marble monuments, surfaces in urban environments) exposed to airborne algae.

Lederberg (1960) first used the term "exobiology" to describe the exploration of life at higher elevations, from the stratosphere into the space field realm. The presence of bacteria, archaea and fungi in the upper troposphere has been reported by Rodriguez et al. (2013). Furthermore, fungi seem to play an important role on epidemiology and climate change by cloud condensation or nucleation (DasSarma et al., 2020). Some bacterial and fungal spores have also been found in the mesosphere and thermosphere, whereas the presence of microalgae in troposphere has been scarcely studied and the unequivocal evidence for algae in the stratosphere and other upper layers has not been found. The study by Zerveas et al. (2021) showed the ability of microalgae to turn hostile atmospheres into O2-rich atmospheres. These primary producers can start a chain of life and can maintain it, as also proposed by Macário et al. (2022), who mentioned cyanobacteria as candidates to support Mars colonization. I strongly believe that an unexplored ecosystem exists in the stratosphere, starting with these primary producers, which might play a relevant role in the earth's environment and changing climate.

Concluding remarks

The atmosphere is considered one of the most extreme environments due to its low nutrient levels, extreme temperatures, and high radiation levels. It is a difficult place to mimic and study, and sampling techniques need to be advanced. In this mini review, we discussed the studied algal diversity in the troposphere and its role, which is supported by valid evidence. However, to fully understand the importance of these primary producers in global climate change and biomass distribution, we need to study all the layers of the atmosphere. In the past few decades, scientists have shown that microbes are ubiquitous, found from the top ionosphere to the deep trenches, and involved in all cycles, such as carbon, nitrogen, and oxygen. This indicates their crucial role in climate change. Nevertheless, there is still much to learn about many microbes and their roles in different ecosystems. Currently, only 0.0001% of microbial diversity is known to humankind. Therefore, exploring microbial diversity in the atmosphere is necessary to understand the exact picture of microbial ecology and its role in climate change.

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