Leonardo da Vinci (1452-1519) and the birth of stratigraphy

Annalisa Ferretti[a*], Francesco Vezzani[b], and Marco Balini[c]

[a] *Dipartimento di Scienze Chimiche e Geologiche, Università degli Studi di Modena e Reggio Emilia, Via Campi 103, 41125 Modena, Italy. ferretti@unimore.it*
[b] *Scuola Galileiana di Studi Superiori, Via S. Massimo 33, 35129 Padova, Italy. francesco_vezzani@yahoo.it*
[c] *Dipartimento di Scienze della Terra "Ardito Desio", Via Mangiagalli 34, 20133 Milano, Italy. marco.balini@unimi.it*
[*] *corresponding author at: Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Via Campi 103, 41125 Modena, Italy. ferretti@unimore.it, ph. ++39 059 2058470 (A. Ferretti).*

Abstract. Most geological handbooks attribute the birth of stratigraphy to William Smith in the 18th century, after a brief mention of the pioneering contribution of Niels Stensen (Nicholaus Stenonis) who, almost a century before, had introduced in his *Dissertationis prodromus* of 1669 the principles of geometric relationships between strata. On the contrary, Leonardo da Vinci is related, among other scientists, to the intuition that fossils are remains of living organisms. Da Vinci was indeed much more than that. All concepts commonly associated with stratigraphy, e.g., fossils as age-diagnostic tools, geometric properties and position of strata, correlations of stratigraphic successions, are deeply-rooted in Leonardo's writings and fully expressed in his paintings, integrated in mature observations and reproduction of the landscape. The celebration of the five-hundredth anniversary of Leonardo's death gives us the opportunity to finally link Leonardo da Vinci to the birth of modern stratigraphy.

Keywords. Leonardo da Vinci, Renaissance, stratigraphy, modern geology, Niels Stensen, William Smith

1. Introduction

Leonardo da Vinci (1452-1519) is universally celebrated as the Renaissance genius. His excellence in Art, with masterpieces that are celebrated all over the world, has obscured many of his achievements in other fields. Leonardo did indeed explore in his life many other disciplines, from engineering to cartography, from anatomy to botany, from military and civil architecture to music and scenography. The anniversary of Leonardo's death, exactly five hundred years ago, offers a unique opportunity to focus on his contribution to geology and, specifically, to stratigraphy.

Leonardo was born in Vinci in 1452 as an illegitimate child, usual condition for the time, shared with, among others, the terrific Cesare Borgia, one of his later clients, who was the illegitimate son of the Pope Alexander VI. With this situation, Leonardo did not receive a formal classical education in Latin and Greek (he often referred to himself as "*homo sanza lettere*"= *man with no education*)

but, as common in that period, his instruction was characterized by a strong permeability and contamination between Math, Art, Music, Engineering and Natural Sciences. This clearly explains Leonardo's versatility and all-encompassing knowledge. In whatever discipline he applied, he always placed the use of observation and direct experience as his starting point (De Lorenzo 1920, Kemp 2006, Zöllner 2007, Capra 2008, Baucon 2010), anticipating of one century the experimental scientific method of Galileo Galilei (1564-1642):

Leonardo, Manuscript E, folio 55r: "*But first I will make some experience ahead, then I will proceed further, because my intention is to first experience and later demonstrate the reason why this experience is thus forced to operate*."(1)

Leonardo, Codex Atlantic, folio 110r: "*Many will reasonably feel to contradict me, […] as my things will derive by only and sole experience, which is a true teacher. I am aware […] that any arrogant man will reasonably blame me, for being without education*."(2)

After a short period in Vinci, Leonardo moved to Florence where he attended the Verrocchio artwork (Fig. 1). There he was given the commission of the first paintings, as *The Adoration of the Magi* and *Saint Jerome in the Wilderness*, both left unfinished as with many other later commissions Leonardo would receive. Today no more than fifteen paintings are entirely or mainly attributable to him (Isaacson 2017). Florence counted at that time 40,000 inhabitants and was a rich center of vivid culture and artistic innovation, with an extraordinarily efficient banking activity; the *fiorino*, a coin renowned for the purity of its gold, was the preferred currency of exchange throughout Europe (Isaacson 2017). It was mainly in Florence and in Milan, where he lived from 1482 to 1499, that most of his geological background was formed. His natural training-field of *sperienza* were the hills and valleys in Tuscany and in the Lombard Prealps (De Lorenzo 1920). After a short stay in Venice, Leonardo returned to Florence in 1500 and, after serving Cesare Borgia in Cesena, he was back in Florence in 1503, when he started working at the *Mona Lisa*. From then on, he moved between Florence, Milan and Rome. In Florence, commissioned by Machiavelli's government, Leonardo worked as a hydraulic engineer. He was asked to make the river Arno navigable after Florence and to divert the Arno from its course before getting to Pisa, following the long lasting opposition between Florence and Pisa (Laurenza 2018). In 1516 Leonardo finally moved to Ambois, in France, where he worked and lived under the service of King Francis I. There he died on 2 May 1519, at the age of 67.

The fifteenth century was in general an epoch of art, inventions, exploration and dissemination of knowledge through new techniques. Filippo Brunelleschi (1377-1446), Michelangelo Buonarroti (1475-1564), Raffaello Sanzio (1483-1520), Donatello (1386-1466), Sandro Botticelli (1445-1510) and Andrea del Verrocchio (1435-1488) are just some of the artists that lived at Leonardo's time, mostly in Florence. Johannes Gutenberg (1400-1468), by introducing mechanical movable type printing to Europe, made possible a large diffusion of books (Fig. 2A). Less than two years away from Leonardo, Cristoforo Colombo (1451-1506) and Amerigo Vespucci (1454-1512) were born. Their discovery of a New World, America, strongly modified geographic knowledge in the Old World (Fig. 2B). In addition, Nicolaus Copernicus (1473-1543) with his heliocentric vision had finally displaced the Earth from the center of the Universe (Fig. 2C).

This long premise is necessary to finally dispel the idea that Leonardo represented a light in the general cultural darkness. Leonardo simply operated in the context of his time (Tab. 1), as underlined by Gould (1998), and his geological ideas must be framed and tuned to the late medieval-Renaissance philosophical sphere. Gould (1998, p. 43): "*Leonardo, the truly brilliant observer, was no spaceman, but a citizen of his own instructive and fascinating time*." Only in this way, we will be able to understand and fully rediscover his contribution to modern stratigraphy.

2. Traditional view on the birth of stratigraphy

Stratigraphy is the branch of geology that deals with bedded successions, consisting usually of sedimentary rocks. Aim of stratigraphy is to understand and explain the organization of beds and to restore their original vertical and lateral variations.

The traditional view on the birth of stratigraphy shows some surprising connections to the life of Leonardo that have never been emphasized. The eclectic scientist Niels Stensen (1638-1686), in Latin Nicholaus Stenonis, is unanimously considered one of the fathers of stratigraphy. During his life he travelled all over Europe, but his outstanding contribution to the history of stratigraphy was realized in Florence, the same town where Leonardo, who also was a tireless traveller, spent the first part of his career. Stensen was invited to stay in Florence by Ferdinando II de' Medici to carry out anatomical studies (e.g., Rudwick 1972). During this stay, Stensen had the opportunity to observe rocks eroded by rivers in the surroundings of the town. These observations led him to enunciate the four basic principles of *strata*, Latin name for beds: original horizontality, original continuity, superposition and cross cutting relationships. These principles were described in his most important paper on geology, published in Florence, *The Solido intra Solidum naturaliter Contento…* (Stenonis 1669), with the support of six simplified but extremely effective geological sections (op. cit. figs. 20-25) summarizing the geological evolution of Tuscany and showing several kinds of bedding relationship.

Stensen's principles have been always regarded as the theoretical basis of stratigraphy, but the practical application of stratigraphy actually started about one century after *The Solido…*, in the mid 18th century with Lehmann (1756) and Füchsel (1761, 1773), who described sedimentary successions in Thuringia and Saxony. The term *strata*, used by Füchsel, who wrote his book in Latin, was included in both the English language and tradition by Hutton in his *Theory of the Earth* (1795), by Smith in his extraordinary contribution *Strata identified by organized fossils* (1816), by Lyell (1830-1833) in his four volumes *Principles of Geology*, and by Philips in his *Treatise on Geology* (1837-1839). Lyell described in his glossary (1833, v. 3, p. 81) the words: *stratified*, *stratification* and *stratum/strata*. Cuvier and Brongniart (1811), masters of the French school, preferred to use *couches* instead of *strata* but kept the term *stratification*, while the German school followed the tradition started by Lehmann (1756) of using *Schichten* (e.g., Alberti 1834, von Buch 1839, Quenstedt 1846-1849).

The term stratigraphy, as a scientific branch of geology, was introduced later, in the mid 19th century (e.g., d'Orbigny 1850, 1852, Oppel 1856-1858), but there is no doubt that the practice of grouping strata into units and their correlations over long distances, the two aims of modern stratigraphy, started with Lehmann and Füchsel and continued with geologists of the end of the 18th-beginning of 19th centuries. Formations and systems were introduced at this time, while the

concepts of guide fossil, stage and zone represent further achievements (see Balini et al. 2017 and references therein).

3. Leonardo and his time

In Renaissance times, the Biblical Theory of Genesis was universally accepted including the assumption that there have always been the same species of animals and plants living on the Earth as originally created by God. The shells found in mountains were considered proof of the existence of the Flood: they were exactly the animals that were submerged and killed by the *Universal Diluvium* or *Deluge*. Furthermore, the *Sacra Scriptura* were describing a stable and immutable Earth. All meteoric and seismic phenomena were terrific cataclysms, modifying the normal stability of Nature, caused directly by God as a sort of punishment (De Lorenzo 1920).

A minor revolution against this prevailing dogma was attempted by the Inorganic Theory, rooted in the Greek philosopher Aristotle (384-322 B.C.) and the Greek School, suggesting that petrified shells, what we now call fossils, were natural curiosities imitating living shapes growing spontaneously in the ground under the effect of a "formative force" (*vis plastica*) (Koutsoukos 2005).

Among a production of about 25 Codices and collections distributed in Italy, France, United Kingdom, Spain and United States (Isaacson 2017), Leonardo's assertions about geology and paleontology are mainly enclosed in the Codex Leicester, compiled primarily in Florence between 1505 and 1509 (Laurenza 2018), as well as documented in visual references and background *scenarios* in his paintings (Rudwick 1972, Kemp 1981, Vai 1995, Gould 1998, Vai 2003, Baucon 2010, Dominici 2017).

The Codex Leicester derives from the assemblage of eighteen large sheets. Each *folio* was folded in two, each about 298 x 223 mm (Laurenza 2018). Folios were composed independently of each other: there is no sentence or concept that goes from one page to another. Because good quality paper was expensive, almost all folios were densely filled by Leonardo with writings for about three-quarters of the space on the page, flanked on the right by a column available for illustrations and notes (Zuffi 1995). Each folio is referred to with a number and a letter, r: *recto*, v: *verso*.

4. Leonardo and stratigraphy

Leonardo expressed his naturalistic observations directly in his sketches and paintings. They record many geological elements, among which beds, successions, turbiditic sequences, sedimentary structures, ichnofossils and weathering processes (see, among others, Vai 1995, Pizzorusso 1996, Vai 2003, Baucon 2010). Leonardo's geological knowledge is documented even in the early drawings of Leonardo, like the famous *Landscape drawing for Santa Maria della Neve on 5th August 1473* (Fig. 3). Compiled when Leonardo was only 21, this sketch reveals an astonishing geologic realism: massive and finely stratified rocks in the landscape view are modeled by river erosion with an impressive fidelity to nature, with erosion structures coexisting with depositional forms (Dominici 2017). Recent X-ray studies indicated that this part has been retouched *a posteriori* by Leonardo himself, after observing the stratification directly in the field, with his everlasting obsession for capturing natural phenomena in their evolution (Nova 2015).

But it is mostly in his masterpieces, by the use of oil painting, that Leonardo was able to provide the best vivid images, like in the *Virgin of the Rocks*, whose two versions have been the subject of a "geological" dispute as the background of the painting exposed in the National Gallery in London, lacking the geological accuracy of the *Virgin* exposed in the Louvre (Fig. 4A), suggests it was painted not by Leonardo (Pizzorusso 1996) but probably by one of his scholars. The geology impressed in the Louvre painting is extraordinary; Leonardo constructed the grotto with sandstones, and located diabase in the background close to the Virgin's head, both sculptured by erosion and covered by the vegetation that would have grown on these rocks (Pizzorusso 1996). Just at the base of the oil, the Child Jesus is sitting on impressive and lively stratified rocks (Fig. 4C), with even a possible evidence of a bioturbation trace (Baucon 2010).

An even more geologically complex interpretation is given in the *Virgin and Child with Saint Anne* (Fig. 5B), where Leonardo details the bottom with a distinct stratification of rounded river stones close to the feet of Saint Anne (Fig. 5D), with also indications of turbiditic cross-lamination (Coccioni 2019).

A so vivid reproduction of nature and details of stratification clearly contrasts with other previous paintings, like Giotto's *Miracle of the Spring* (ca. 1295-1299; Fig. 5A) where rocks appear to have almost no identity, such as the entire background, so that the observer is forced to focus on the only religious subject. But Leonardo was not the first in such a vivid reproduction of Nature and geological details. The Flemish School, probably well-known in Verrocchio's workshop, had already experienced this careful naturalistic reproduction of the rocks. In the *Saint Francis of Assisi receiving the stigmata* by Jan van Eyck (1428-1429; Fig. 5B), remarkable are the details of the stratification (Fig. 5C) and even the possible presence of fossils (Fig. 5D), specifically brachiopods or bivalves, within the boulders close to Brother Leo in the bottom right of the painting (Dominici 2017). In addition, other Italian painters like Andrea Mantegna (1431-1506) were experiencing a similar approach to their landscapes (Vai 2003a, 2009).

We have therefore to concentrate on Leonardo's writings to finally realize that Leonardo da Vinci had clearly understood: i) the fallacy of the *Diluvium* and the real significance of fossils; ii) the mechanisms of sedimentary deposition; iii) the role that rivers play in the erosion of land, and iv) the laws of superposition and correlation.

4.1. Leonardo and Diluvium

The strong refutation of the Noah's *Diluvium* proposed by the Bible forms a major part of the Codex Leicester of Leonardo, with full pages of text dedicated just to this topic. What is remarkable is that Leonardo opposed the *Deluge* with a profusion of different arguments, based, for example, on the simple physical consideration that a universal flood would have equally covered the spherical Earth with a uniform level of water at the same altitude, with no gradient and thus no way for the water to flow down:

Leonardo, Codex Atlantic, folio 152a: "*A doubt arises here, and this is whether the Flood that came at the time of Noah was universal or not, and here it will seem not for the reasons which will be assigned. We in the Bible have that the aforementioned Flood was constituted of 40 days and 40 nights of continuous and universal rain, and that such rain raised six "gomiti" above the highest mountain of the universe; and if so […] it covered our earth of spherical figure, and the spherical*

surface has every part equally distant from the center of the sphere; being the sphere made of water in the said condition, it is impossible for the water above to move, because the water itself does not move, if unable to descend; so how was the water of the Flood able to leave, if here it is proved not to have motion? And if it left, how did it move, if it could not go upstream? And here there are no natural reasons, so it is necessary for solving this doubt, to call the miracle for help, or to say that this water was vaporized by the heat of the sun."(3)

Leonardo often questioned the *Diluvium* using fossils (*nichi=molluscs*), with an amazing modern taphonomic approach, highlighting for instance that a single flood would have produced a mixture of shells and not regular ordered beds:

Leonardo, Codex Leicester, folio 8v, chapter "*del diluvio e de' nichi marini=about Flood and marine shells*": "*Further on was deposited the mud in which the shells lived, which rose by degrees according to the levels of the Arno which flowed into the more or less turbid sea. And from time to time, the sea bottom rose, depositing these shells in layers, as can be seen in the cut at Gonzoli Hill, eroded by the Arno which is wearing away its base, in which cut the aforesaid layers of shells can be seen in bluish clay, along with other marine objects […] If the shells had instead been transported by the muddy deluge they would have been mixed, arranged separately in the mud, and not in ordered steps and layers, as we see them now.*"(4)

Later on, in the same Codex Leicester, Leonardo denies once more the *Deluge*, stating that one flood should produce a fossil record in a single layer. On the contrary, the presence of fossils in several superposed layers proves their deposition occurred at different and following times:

Leonardo, Codex Leicester, folio 10r*: "And if the flood had brought them in such sites from the sea, you would find shells at the base of a single bed, and not at the base of many, where it is possible to list the succession of the years […] And if you want to say that the more floods have produced these beds, and shells infra them, it would be necessary to admit that such a flood happened every year."*(5)

Paradoxically, in his later years in France Leonardo was much engaged in portraying images of cataclysm and realized a series of eleven drawings of a mighty *Deluge*, each showing a landscape flooded by a vast tempest (Fig. 6A).

4.2. Leonardo and fossils

Leonardo provides in his writings one of the most brilliant and vivid explanation of the process of fossilization: fossils are organisms that were alive when submerged by the mud, that later dried and, with time, petrified in rocks.

Leonardo, Codex Leicester, folio 10r*: "And within beds […] and inside stones, shells are found isolated and in pairs, like those that were left by the sea, buried alive in the mud, which then dried up and in time became petrified."*(6)

Leonardo, Manuscript F, folio 79 and 80: "*When the inundation of muddy rivers discharged thin mud over the animals, that live under the waters near the marine sites, the animals were affected by such mud and forced to die, lacking the animals they used to eat. And as the sea lowered with time, this mud was […] converted into stone, and the shell portions of these shells, since their animals had already been consumed, became filled in again with mud in place of those. And so, in the transforming of all the surrounding mud into stone, this mud as well, which remained within the coverings of the somewhat opened shells […] this also came to be converted into stone. And in this manner, all the coverings of these shells were left between the two beds, that is, between that which enclosed them and that which they enclosed.*"(7)

Leonardo also disputed those proposing an astral origin of fossils with, again, a surprising taphonomic approach:

Leonardo, Codex Leicester, folio 9r: "*For those who claim that shells are […] born far from the seas […] to those we will reply that […] this cannot happen […] if not for animals having same size and age, not the old with the young, nor one with an outer covering and another without its covering, nor one broken and another whole, one filled with sea sand, and with other coarse and fine shell fragments inside the whole shells, which there remained.*"(8)

In spite of such a vivid identification of the basic mechanism of fossilization, Leonardo hardly left drawings of fossils, apart from a small sketch possibly attributed to a *Paleodictyon* in folio 25r of the Codex I (Fig. 6B), a trace left by bioturbation (Cioppi 2006, Baucon 2010). But Leonardo, again, provided in his writings a clear idea of the process:

Leonardo, Codex Leicester, folio 10r: "*How between the various layers of stone are still to be found the tracks of the worms which crawled about upon them when it was not yet dry*."(9)

4.3. Leonardo as fluvial engineer

Leonardo was fascinated by rivers and dedicated a lot of time to their study, in all respects and at different scales. As in other fields, he was able to use his personal knowledge based on extremely accurate observations, either at a rational level, to design and realize innovative, top-level, technical applications, but also at an emotional level by composing with rivers peculiar landscapes for the background of some of his best charming, delicate but stunning, fascinating and magnetic paintings (see Introduction to chapter 4).

As a scholar of Nature in general, and of rivers in particular, Leonardo very carefully analyzed different types of water flows, as documented in famous sketches (Fig. 7A) now mostly included in the Codex Windsor. He correctly understood the size sorting and the roundening of the grains transported by rivers (Codex Leicester, see next chapter). He mapped rivers at a very small scale, with a fantastic accuracy, as documented for instance, by the map of Imola (1502; Fig. 7B). In this map, Leonardo showed the point bar deposits and the cut banks of the meanders of the Santerno River, their lateral migration, as well as the changes in the position of the main stream from meander to meander (Fig. 7C).

At larger scale, Leonardo provided extremely accurate topographic maps of the rivers of Tuscany and Lombardy. His understanding of topography and his extraordinary perception of the three dimensions, allowed him to draw 3D, oblique views of the landscape of Valdichiana, Tuscany (Fig. 7D) emphasizing the combination of the drainage system by rivers and the different elevation of the hills (Windsor RL 12628) that were very innovative for his time.

Leonardo's deep knowledge of water flows, erosional and sedimentary processes, and topography allowed him to become one of the most requested fluvial engineer of his time. In this respect, the similarity between Leonardo and William Smith (1769-1839), another father of stratigraphy, is really impressive. Leonardo was in charge of some highly ambitious canal projects in Italy: the preliminary project for a canal connecting Florence to the sea (1473-1513; Fig. 7E); the preliminary project for a canal connecting Lake Como and Milano (1482); the connection of the two *Navigli* (canals in the Italian language) downtown Milano (1506-1513) with new very innovative type of locks (e.g., Codex Atlantic folio 656a); a challenging preliminary project (1516) for a canal connecting Adda river north of Paderno, to Milano, involving the building of a dam on the Adda river and a tunnel. This list of projects reveals that Leonardo had a different type of fluvial engineering expertise with respect to W. Smith. The latter was very successful in planning new canals and in realizing the following excavations, with on-site supervision. Leonardo, instead, was often asked to find the solution for difficult and challenging tasks, but he was not in charge of following a construction site of a canal on a daily basis. Even in fluvial engineering, Leonardo was credited as a genius by his contemporaries.

4.4. Beds as sedimentary rocks

Stensen was the first to publish about *strata* and the four basic principles of stratification. He also described (Stenonis 1669, p. 26-37) the process of formation of *strata* by the erosion of rocks, the transport by gravity and fluids, and sedimentation, as well as the possible incorporation of animals and plants during these processes. The similarity with the observations made by Leonardo more than 150 years earlier is impressive. The fact that Leonardo and Stensen came to the same conclusion on the origin and formation of strata more than 150 years apart, might reflect the abundance of easy to understand outcrops in the surroundings of the town, but also the fact that over that time, under the Medici's rule, Florence was an international centre for culture, science and art.

In some respects, Leonardo was a more accurate sedimentologist than Stensen, as documented by the following description:

Leonardo, Codex Leicester, folio 6v: *"When a river flows out from among mountains it deposits a great quantity of large stones [...] And these stones still retain some part of their angles and sides; and as it proceeds on its course it carries with it the lesser stones with angles more worn away, and so the large stones become smaller; and farther on it deposits first coarse and then fine gravel [...] until at last the sand becomes so fine as to seem almost like water [...] and this is the white earth that is used for making jugs."*(10)

His outstanding description of sedimentology in fluvial environments, combined with his realistic representation of sedimentary beds in his paintings and his understanding of the origin of fossils and distribution of fossils in beds, demonstrate out of any doubts that Leonardo had an extremely modern and integrated knowledge of *strata* as sedimentary rock bodies. In his writings,

however, he never used the term *strata*. This is not surprising, because *strata* is a Latin word, and he wrote in Italian not in Latin. He used to refer to stratified rocks as *pietre faldate* (e.g., Codex Leicester, folio 10*r*; see also next chapter), but the meaning is exactly the same, being *falda* a thin body with a very wide lateral continuation.

4.5. Superposition, Time and Correlation

Leonardo's view on the vertical and lateral organization of beds, based on comparisons of the sides of the valleys sculptured by rivers (Laurenza 2018), was also extremely correct and basically equivalent to that of Stensen. In this regard, what Leonardo wrote in folio 10r of the Codex Leicester is self-explaining and does not need any further comment (see also sub-chapter 4.1):

Leonardo, Codex Leicester, folio 10r: "*How the rivers have all sawn through and divided the members of the great Alps one from another; and this is revealed by the arrangement of the stratified rocks, in which from the summit of the mountain down to the river one sees the beds on the one side of the river corresponding with those on the other. How the beds ["pietre faldate"] on the mountains are formed by all the variety of mud, superposed one by one because of the river floods. How the different thickness of the beds are formed by different types of flooding, that is to say major or minor flooding. How between the beds we may still recognize the traces left by worm, that used to move in between these beds when they were not yet dry. How all the marine mud still retain molluscs, and shells are petrified together with the mud.*"[(11)]

4.6. Evolution of the Earth

All the above recognitions are not simple achievements but the fundamental frames to support a more global vision by Leonardo of an Earth that had radically evolved over time, in analogy with a living creature. "*It is a body, just like the body of man and animals, that undergoes processes of generation and corruption*" (Laurenza 2015, p. 257). "*Water is the agent responsible for terrestrial transformations, in both the short and long term, like blood in the human body. Bones and blood correspond to rocks and water in Leonardo's macrocosm*" (Cioppi and Dominici 2018, p. 179; Fig. 6C).

This is clearly in contrast with the Biblic vision of an unsteady planet kept immutable since God had created it. Surprisingly, most of Leonardo's conclusions were founded just on marine fossils present in mountains. Under this perspective, rivers are the blood vessels of the Earth's body, giving life and death to mountains:

Leonardo, Codex Atlantic, folio a: "*Mountains are made by rivers; mountains are destroyed by rains and rivers*."[(12)]

On a local scale, Leonardo projected the Mediterranean Sea to a past vision of a quite different landscape:

Leonardo, Codex Leicester, folio 10v: "*In the Mediterranean [...] the peaks of the Apennines emerged in the form of islands, surrounded by salted waters [...] and above the plains of Italy, where today flocks of birds are flying, fish were swimming in large shoals.*"[(13)]

But Leonardo provides also a more global vision of the Earth, just when the Florentine Amerigo Vespucci had finally realized that Colombo had discovered a new continent, and relationships between known land and water had to be dramatically changed (Laurenza 2018). Leonardo started investigating in the Codex Leicester the structure of the Earth, how it had formed in the past and how lands and seas can possibly evolve in the future, proposing a marvellous process of balancing between mass collapses from the northern to the southern hemisphere and land rising from the water to the northern hemisphere (Fig. 6D-E), to finally keep the Earth stable at the centre of the universe (Laurenza 2015, 2018).

5. Leonardo after Leonardo

Leonardo's writings were often hard to decipher for the use both of the Italian language, in a time when Latin was the official language of scholars, and the application of a specular calligraphy (Fig. 6F). This certainly has somehow hampered a full knowledge and diffusion of Leonardo's ideas. After Leonardo's death, his notes were scattered to libraries and collections all over Europe. While sections of Leonardo's technical treatises on painting were published as early as 1651, much of his scientific work, such as the Codex Leicester containing major assertions about geology and paleontology, was made public only at the end of the 19th Century. The first citation of the Codex Leicester in a geological context dates to the late 1800s chapter III of the sixth edition of Charles Lyell's *Principles of Geology* (Vai 2003b) and the full publication of his private notebooks in the 1880s (Gould 1998), even though some copies probably were circulating in Europe in the 18th century, reflecting in normal script Leonardo's specular calligraphy (Laurenza 2018). It is indeed highly probable that Leonardo's geological ideas circulated by verbal transmission or informally within restricted groups of friends, especially in Florence, Milan, and Amboise, as suggested by the arguments given in a letter by Girolamo Fracastoro (1485-1553) to deny the *Diluvium*, perfectly matching Leonardo's views (Vai 2003b). Similarly, we cannot exclude that Niels Stensen himself could have come in touch with Leonardo's ideas during his stay in Florence, and his study at the Medici's collections and library (Vai 2009).

Laurenza (2015, p. 267) even suggested a possible influence of Leonardo on the birth of modern geology, between the end of the 17th and the early 18th century: "*This was also the period in which, after two centuries of oblivion, the Codex Leicester reemerged and began to circulate. In 1689, the painter Giuseppe Ghezzi acquired it in Rome from the heirs of the sculptor Guglielmo della Porta. Then, in around 1717, the Codex was acquired by an English nobleman, Thomas Coke, later the Earl of Leicester, who moved it first to Florence and then to London. In the same period, various copies of the Codex were realized, which are historically important because they made Leonardo's idiosyncratic mirror writing understandable, potentially enlarging his circle of readers to include scientists. These coincidences suggest a possible role played by the Codex in the development of geology and of modern science more generally.*"

However, any inferences on Leonardo's impact either on Niels Stensen and modern geology remain so far conjectural. Since the official release of the Codex Leicester with the first publication of the complete transcription in 1909 (Cioppi and Dominici 2018), several books and articles have

been published (see, among many others, De Lorenzo 1920, Rudwick 1972, Ligabue 1977, Kemp 1981, Vai 1995, Vai 2003, Kemp 2006, Kemp 2011, Laurenza 2015, Cioppi and Dominici 2018, Dominici and Cioppi 2018, Laurenza 2018, Kemp 2019). Among them, the accurate and objective analysis that De Lorenzo (1920) made on Leonardo and geology, again using the Italian language and somehow preventing a global diffusion, still stands as a masterpiece. The Codex was finally purchased by Bill Gates on November 11, 1994.

6. Leonardo as the precursor or the founder of stratigraphy?

It is clear that Leonardo had understood the basic principles of stratigraphy, from the way sedimentary rocks are formed and destroyed, to the role played by rivers in the erosion of land, to the significance of fossils as age-diagnostic and environmental tools, to the possibility of tracing beds and sequences over long distances. These, for Leonardo, were not simple discoveries but demonstrations of the Earth changing and that will also change, to reveal that the Earth has evolved.

In his thorough analysis, De Lorenzo (1920, p. 7) regarded Leonardo as a "*lonely and unknown precursor of modern geology*". A now possible dangerous approach, in the effort to find at all costs a "time-zero" in the origin of a discipline, is to claim the birth of stratigraphy to Leonardo himself, as we provocatively titled this chapter. This is far from our intention. Scientific progress may proceed through a sort of "relay", with each runner passing the baton to the next athlete, in other words as a team-work possibly done in different places and in different times. And this happened independently of the ability of each scientist to create or not a circle of followers. All do contribute equally to the final success.

At the end, we cannot avoid wondering if Leonardo's excellence in Art obscured his contributions in other fields. Would we have given more attention to or on the contrary completely ignored his geologic ideas, if Leonardo was not Leonardo?

7. Conclusions

On June 12, 2005 Steve Jobs closed his talk at the Stanford University with the famous words "Stay hungry. Stay foolish". This is perhaps the best way to define Leonardo and his passion for knowledge. As correctly identified by Isaacson (2017, p. 16), Leonardo lived "*his diversity of illegitimate, gay, vegetarian, left-handed, easy to distraction and occasionally heretic [...] Leonardo's insatiable curiosity and continuous experimentation remind us of the importance of [...] thinking differently.*"

Five hundred years have passed since his death, yet Leonardo is rediscovered time after time. The *Salvator Mundi*, known also as "The Last Leonardo", was finally assigned to Leonardo only in 2010. It is now time to finally acknowledge Leonardo's immense contribution to modern stratigraphy.

8. Acknowledgements

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9. References

Alberti, F.v., 1834. Beitrag zu einer monographie des Bunten Sandsteins, Muschelkalks und Keupers und die Verbindung dieser Gebilde zu einer Formation. Verlag der J.G. Cotta'sschen Buchhandlung, Stuttgart und Tubingen, 366 p.

Balini, M., Ferretti, A., Finney, S., Monechi, S., 2017. The contribution of fossils to chronostratigraphy, 150 years after Albert Oppel. Lethaia 50, p. 323–335.

Baucon, A., 2010. Leonardo Da Vinci, the founding father of ichnology. PALAIOS 25, p. 361–367.

Capra, F., 2008. The Science of Leonardo: Inside the Mind of the Great Genius of the Renaissance. Doubleday Books, Danvers, 352 p.

Cioppi, E., 2006. Catalogue entries IV.4D.g, and V.7B. c1-7. In: Galluzzi P. (Ed.), The mind of Leonardo [The universal genius at work], Giunti, Firenze, p. 288–290.

Cioppi, E., Dominici, S., 2018. Fossils and landscape forms in Leonardo's living Tuscany. In: Galluzzi, P. (Ed.), Leonardo da Vinci's Codex Leicester: Water as Microscope of Nature. Giunti, Firenze, p. 171–183.

Coccioni, R., 2019. I dettagli geologici di Leonardo. VivArte, 6 p.

Cuvier, G., Brongniart, A., 1811. Essai sur la Géographie Minéralogique des environs de Paris. Baudouin, Paris, 278 p.

De Lorenzo, G., 1920. Leonardo da Vinci e la geologia. N. Zanichelli, Bologna, 195 p.

Dominici, S., 2017. Ricomposizione del mondo in un paesaggio di Leonardo. Giornale di bordo di storia, letteratura ed arte 42-43, p. 1–18.

Dominici, S., Cioppi, E., 2018. All is not lost: History from fossils and catalogues at the Museum of Natural History, University of Florence. In: Rosenberg, G.D., Clary, R.M. (Eds.), Museums at the Forefront of the History and Philosophy of Geology: History Made, History in the Making. Geological Society of America Special Paper 535, p. 59–80.

Füchsel, G.C., 1761. Historia Terrae et Maris, ex historia Thuringiae, per montium descriptionem. Actorum academiae electoralis moguntinae scientiarum utilium quae Erfordiae est 2, p. 44-208.

Füchsel, G.C., 1773. Entwurf zu der ältesten Erd- und Menschengeschichte, nebst Versuch, den Ursprung der Sprache zu finden. Frankfurt und Leipzig, 273 p.

Gould, S.J., 1998. Leonardo's Mountain of Clams and the Diet of Worms. Essays on Natural History. The Belknap Press, Cambridge, London, 422 p.

Giberti, M., 2016. Leonardo da Vinci e la pianta di Imola del 1473. Studio critico sulla attribuzione a Danesio Maineri. Il Nuovo Diario Messaggero, Imola, 50 p.

Hutton, J., 1795. Theory of the Earth. 2 volumes. Calder Junior and Davies, London, and Creech Edinburgh, 620 and 597 p.
Isaacson, W., 2017. Leonardo da Vinci. Mondadori, Milano, 520 p.
Kemp, M., 1981. Leonardo da Vinci. The Marvellous Works of Nature and Man. Harvard University Press, London, Dent, 384 p.
Kemp, M., 2006. Leonardo da Vinci: Experience, Experiment, and Design. Princeton University Press, Princeton, New Jersey, 224 p.
Kemp, M., 2011. Leonardo. Oxford University Press, Oxford, 328 p.
Kemp, M., 2019. 50 anni con Leonardo. Lucidità e follie attorno all'opera di un genio. Mondadori Electa Editore, Milano, 239 p.
Koutsoukos, E.A.M., 2005. Stratigraphy: Evolution of a Concept. In: Koutsoukos, E.A.M. (Ed.), Applied Stratigraphy, Springer, p. 3–19.
Laurenza, D., 2015. Leonardo's theory of the earth: unexplored issues in geology from the Codex Leicester. In: Frosini, F., and Nova, A. (Eds.), Leonardo da Vinci on Nature: Knowledge and Representation. Studi e Ricerche 11, Marsilio, Venezia, p. 257-267, 388-391.
Laurenza, D., 2018. Leonardo da Vinci - The Codex Leicester, Giunti Editore, Firenze, Milano, 104 p.
Lehmann, J.B., 1756. Versuch einer Geschichte von Flötz-Gebürgen. Berlin, 342 p.
Ligabue, G., 1977. Leonardo da Vinci e i fossili. Neri Pozza Editore, Vicenza, 92 p.
Lyell, C., 1830-1833. Principles of Geology, Being an Attempt to Explain the Former Changes of the Earth Surface, by Reference to Causes Now in Operation. V. 1 (1830), V. 2 (1832), V. 3 (1833), John Murray, London.
Nova, A., 2015. «Addj 5 daghossto 1473»: l'oggetto e le sue interpretazioni. In: Frosini, F., and Nova, A. (Eds.), Leonardo da Vinci on Nature: Knowledge and Representation. Studi e Ricerche 11, Marsilio, Venezia, p. 285-301, 398-412.
Oppel, A., 1856-1858. Die Juraformation Englands, Frankreichs und des südwestlichen Deutschlands. Ebner & Seubert, Stuttgart, 857 p.
d'Orbigny, A., 1850. Prodrome de Paléontologie stratigrahique universelle. Masson, Paris, V. 1, 394 p., V. 2, 428 p.
d'Orbigny, A., 1852. Cours élémentaire de Paléontologie et Géologie stratigraphiques. Masson, Paris, V. 2 (2), 847 p.
Philips, J., 1837-1839. Treatise on Geology. Longman, Orma, Brown, Green & Longmans, Paternoster. Row, and John Taylor. V. 1 (1837), 334 p., V. 2 (1839), 308 p.
Pizzorusso, A., 1996. Leonardo's Geology: The authenticity of the *Virgin of the Rocks*. Leonardo 29, 197-200.
Quenstedt, F.A., 1846-1849. Petrefactenkunde Deutschlands. Tübingen, 581 p.
Rudwick, M.J.S., 1972. The Meaning of Fossils: Episodes in the History of Palaeontology. University of Chicago Press, Chicago, 287 p.
Smith, W., 1816. Strata identified by organized fossils. Arding, London, 32 p.
Stenonis, N., 1669. De Solido intra Solidum naturaliter Contento, Dissertationis prodromus. Insegna della Stella, Florentiae, 78 p.
Vai, G.B., 1995. Geological priorities in Leonardo da Vinci's notebooks and paintings.In: Giglia, G., Maccagni, C., and Morello, N. (Eds.), Rocks, Fossils and History: Inhigeo, Festina Lente, Firenze, 13–26.

Vai, G.B., 2003a. I viaggi di Leonardo lungo le valli romagnole: Riflessi di geologia nei quadri, disegni e codici. In: Leonardo, Machiavelli, Cesare Borgia: Arte, Storia e Scienza in Romagna (1500–1503). Roma, De Luca Editori d'Arte, p. 37–47.
Vai, G.B., 2003b. A liberal diluvianism. In: Vai, G.B., and Cavazza, W. (Eds.), Four Centuries of the Word Geology: Ulisse Aldrovandi 1603 in Bologna. Bologna, Minerva Edizioni, p. 220–249.
Vai, G.B., 2009. The scientific revolution and Nicholas Steno's twofold conversion. In: Rosenberg, G.D. (Ed.), The Revolution in Geology from the Renaissance to the Enlightenment, Geological Society of America Memoir 203, p. 175–196.
von Buch, L., 1839. Über den Jura in Deutschland. Physikalische Abhandlungen der königlichen Akademie der Wissenschafien zu Berlin Jahrgang 1837, 49–135.
Zöllner, F., 2007. Leonardo da Vinci: 1452–1519: The Complete Paintings and Drawings. Taschen, Köln, 695 p.
Zuffi, S., 1995. Le acque, la terra e il cielo nella storia universale del mondo. In: Leonardo da Vinci. Della Natura, peso e moto delle acque. Il codice Leicester. Milano, p. 23–33.

10. Figure Captions, Table Captions

Fig. 0: COVER. Leonardo da Vinci: self-portrait in Red Chalk (ca. 1512; Royal Library of Turin, Turin).

Fig. 1. Leonardo da Vinci during his stay in Florence. A. Detail of the bronze statue of *David*, Andrea del Verrocchio (1473-1475, Museo del Bargello, Florence); Verrocchio modelled the statue after a pupil of his workshop, probably the young Leonardo himself. B) Self-portrait of Leonardo in the *Adoration of the Magi*, Leonardo da Vinci (1481, Uffizi, Florence).

Fig. 2. A) Reconstruction of the movable-type printing press introduced by Johannes Gutenberg, enabling the Printing Revolution. B) New World map by Theodor de Bry (1596). C) Heliocentric model from Nicolaus Copernicus' *De revolutionibus orbium coelestium*.

Fig. 3. *Landscape drawing for Santa Maria della Neve on 5th August 1473*, Leonardo da Vinci (1473, Uffizi, Florence).

Fig. 4. A) *Virgin of the Rocks*, Leonardo da Vinci (1483-1486, Louvre, Paris). B) *The Virgin and Child with Saint Anne*, Leonardo da Vinci (1510-1513, Louvre, Paris). C) Detail of the lower part of the *Virgin of the Rocks* illustrating the Child Jesus sitting on impressive and lively stratified rocks, with a possible evidence of bioturbation (white arrow). D) Detail at the bottom of *The Virgin and Child with Saint Anne* revealing rounded river stones close to the feet of Saint Anne.

Fig. 5. A) *Miracle of the Spring*, Giotto (ca. 1295-1299, Basilica of Saint Francis of Assisi, Assisi). B-D) *Saint Francis of Assisi receiving the stigmata*, Jan van Eyck (1428-1429, Philadelphia Museum of Art, Philadelphia).

Fig. 6. A) *A Deluge*, Leonardo da Vinci (ca. 1517-1518, Royal Collection, United Kingdom). B) Possible *Paleodictyon* sketch, Leonardo da Vinci (ca. 1496-1497, Codex I, detail of folio 25r, Institute de France, Paris). C) Blood vessels of an old and young man, Leonardo da Vinci (ca. 1507-1508, Royal Collection, United Kingdom). D) Folio 36r of Codex Leicester, Leonardo da Vinci (ca. 1505-1509, Seattle, Bill and Melinda Gates Collection). E) *Representation of the Earth*, detail of D). F) Mirror writing by Leonardo da Vinci, detail of the bottom part of D).

Fig. 7. A) Leonardo was fascinated by water flows, eddies and swirls. He dedicated several drawings to the study of the effects of obstacles on water flows, here an example (Codex Windsor, 12660r). B) Map of Imola drawn by Leonardo in 1502 while he was charged by Cesare Borgia to study improvements of the fortifications of the town. Leonardo possibly used an earlier map (1473) by Danesio Maineri (Giberti 2016) (London, Royal Collection RCIN 912686). C) Detail of figure B, showing the meanders of the Santerno River, with accurate mapping of point bars, cut bars and position of the main stream. D) Three dimensions, oblique view of Valdichiana (Windsor RL 12682). E) Map of the Arno River and its tributaries from Florence (lower right corner of the map) and Pisa (last village along the Arno River, on the left side of the map). Leonardo carefully studied the options to connect Florence to the Tyrrhenian Sea, bypassing Pisa, historical enemy of Florence.

649 The path of the canal is traced with a light pencil (here highlighted by arrows), and forms a wide
650 arch from Florence to the north, then to the SW to cross Arno River between Vicopisano and
651 Cascina, then to the WSW to the sea (Codex Madrid II, folios 22v-23r).
652
653 **Tab. 1.** Main events in Leonardo's life and his time (compiled after Baucon 2010, Isaacson 2017,
654 Laurenza 2018). For Leonardo's masterpieces, only the year when the work was begun is indicated
655 (after Kemp 2011 and Kemp 2019).
656
657
658


A
B

Fig. 1

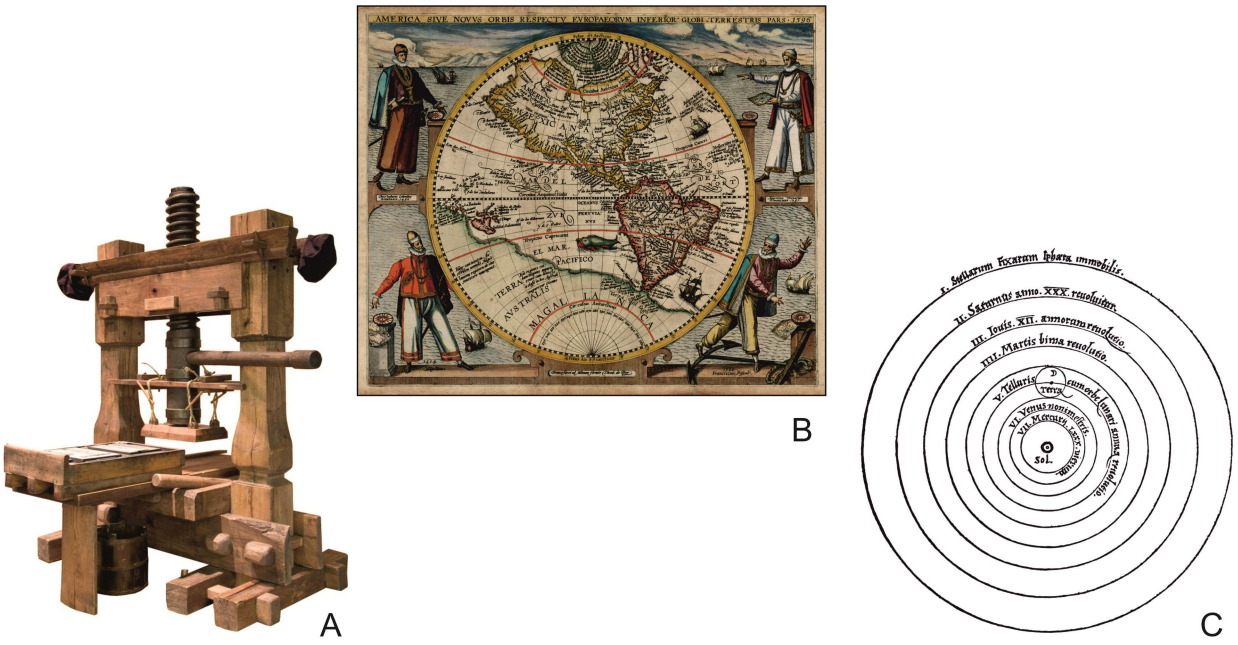
AMERICA SIVE NOVVS ORBIS RESPECTV EVROPAEORVM INFERIOR GLOBI TERRESTRIS PARS
PACIFICO
TERRA AVSTRALIS MAGALLANICA
I. Stellarum Firmarum Sphæra immobilis.
II. Saturnus xxviii. XXX. revolvitur.
III. Jovis. XII. annorum revolutio.
IIII. Martis bima revolutio.
V. Telluris cum orbe Lunari annua revolutio.
VI. Veneris nonima circa
VII. Mercurii LXXX. circa
Sol.
A
B
C

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

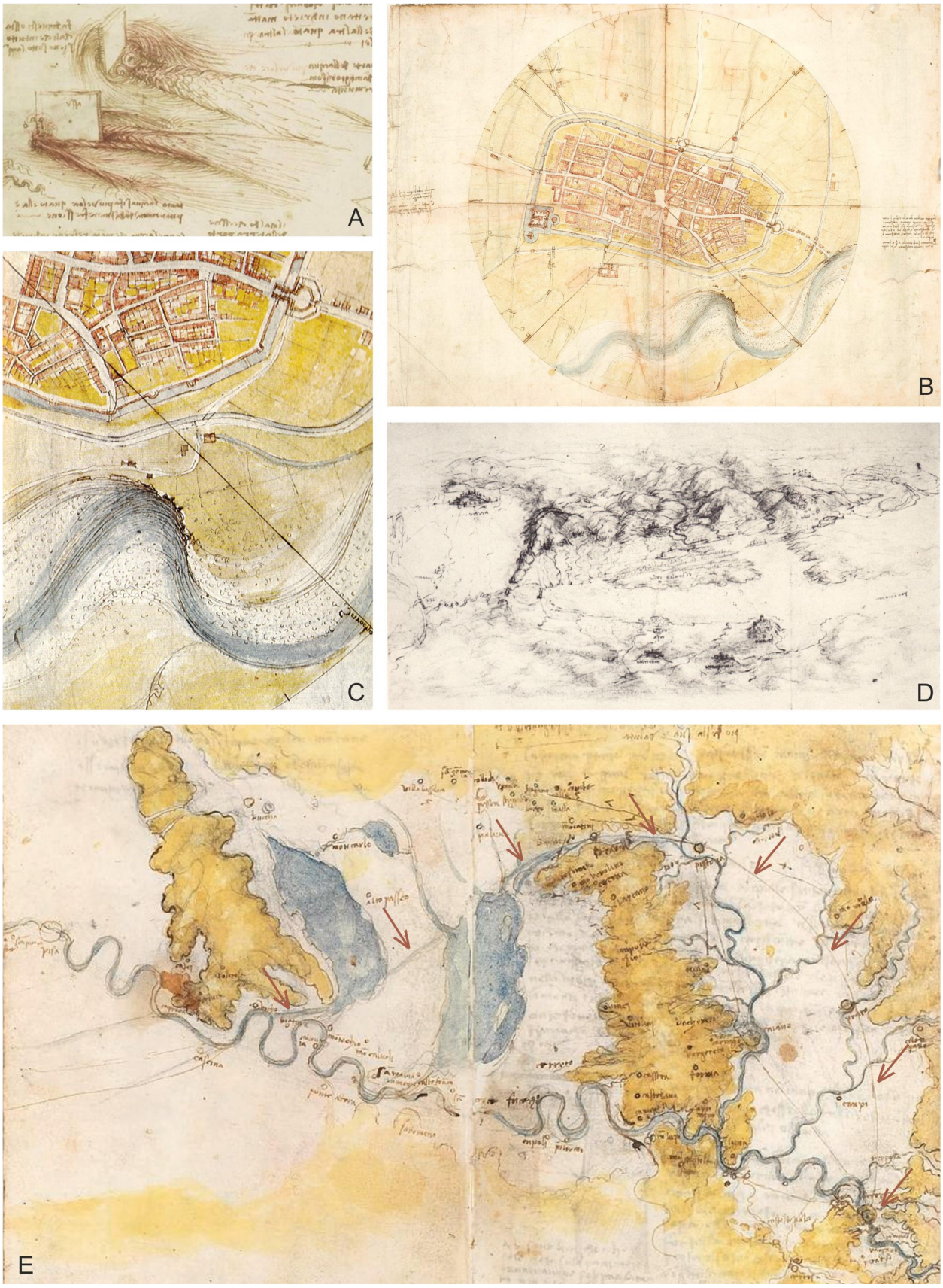

Fig. 7

YEAR	VENUE	MAIN EVENT	COMMITMENTS	LEONARDO'S MASTERPIECES
1452–1481	Vinci, Florence	Apprenticeship and youth in Tuscany	Service at the workshop of Andrea del Verrocchio	**1473** *Landscape drawing for Santa Maria della Neve on 5th August 1473* **1480** *Saint Jerome in the Wilderness*
1482–1499	Milan	Leonardo in Milan	Service as an engineer and artist at the court of Lodovico Sforza	**1483** *Virgin of the Rocks* (Paris) **1485** *Vitruvian Man* **1490** *Lady with an Ermine* **1495** *The Last Supper* **1496** *La belle ferronnière*
1500–1506	Florence	Return to Florence		**1501** *The Madonna of the Yarnwinder*
1502	Romagna, including Urbino, Cesena, Porto Cesenatico, Pesaro and Rimini	Travels in Central Italy	Service as a military engineer and cartographer at the court of Cesare Borgia	
1503	Florence, Pisa		Hydraulic engineer under Machiavelli's government	**1503** *Monna Lisa*
1504	Piombino		Design of fortifications and drainage of wetlands	**1506** *Salvator Mundi*
1504–1505	Studies on bird flight in the hills near Florence and Fiesole			**1505 CODEX LEICESTER**
1506–1512	Milan and Florence	Travels between Milan under the new French court and Florence		**1508** *The Virgin and Child with Saint Anne* (Paris) **1512** self-portrait (Turin)
1513–1515	Rome, Vatican		Service under Giuliano de' Medici, brother of the Pope Leo X, son of Lorenzo the Magnificent	
1516–1519†	Amboise (France)		Service as a painter, architect and engineer at the Court of Francis I, King of France	

1455 Gutenberg's Bible is published

1473 birth of Nicolaus Copernicus

1475 birth of Michelangelo Buonarroti

1492 Colombo reaches what he thinks is India

1501 Vespucci realizes Colombo had discovered a new continent, later named after him

1501 Michelangelo starts working on the *David*

1506 Colombo dies

1508-1512 Michelangelo paints the Sistine Chapel ceiling

1512 Copernicus places the sun at the center of the solar system

680

681 Tab. 1

682

Leonardo da Vinci (1452-1519) and the birth of stratigraphy
SUPPLEMENTARY ONLINE MATERIAL

Annalisa Ferretti[a*], Francesco Vezzani[b], and Marco Balini[c]

[a] *Dipartimento di Scienze Chimiche e Geologiche, Università degli Studi di Modena e Reggio Emilia, Via Campi 103, 41125 Modena, Italy. ferretti@unimore.it*
[b] *Scuola Galileiana di Studi Superiori, Via S. Massimo 33, 35129 Padova, Italy. francesco_vezzani@yahoo.it*
[c] *Dipartimento di Scienze della Terra "Ardito Desio", Via Mangiagalli 34, 20133 Milano, Italy. marco.balini@unimi.it*
[*] *corresponding author at: Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Via Campi 103, 41125 Modena, Italy. ferretti@unimore.it, ph. ++39 059 2058470 (A. Ferretti).*

LEONARDO'S ORIGINAL WRITINGS (after De Lorenzo 1920)

(1) Leonardo, Manuscript E, folio 55r: "*Ma prima farò alcuna esperienza avanti, ch'io più oltre proceda, perché mia intenzione è allegare prima l'esperienza e poi colla ragione dimostrare, perché tale esperienza è costretta in tal modo ad operare*."

(2) Leonardo, Codex Atlantic, folio 110r: "*Molti mi crederanno ragionevolmente potere riprendere, […] non considerando le mie cose essere nate sotto la semplice e mera sperienza, la quale è maestra vera. So bene […] che alcuno prosuntuoso gli parrà ragionevolmente potermi biasimare, coll'allegare essere io omo sanza lettere*."

(3) Leonardo, Codex Atlantic, folio 152a: "*Movesi qui un dubbio, e questo è se 'l diluvio venuto al tempo di Noè fu universale o no, e qui parrà di no per le ragioni, che si assegneranno. Noi nella Bibbia abbiamo che il predetto diluvio fu composto di 40 dì e 40 nocte di continua e universa pioggia, e che tal pioggia alzò di sei gomiti sopra al più alto monte dell'universo; e se così fu […] ella vestì di sé la nostra terra di figura sperica, e la superfizie sperica ha ogni sua parte egualmente distante al centro della sua spera; onde la spera dell'acqua trovandosi nel modo della detta condizione, elli è impossibile che l'acqua sopra di lei si mova, perché l'acqua in sé non si move, s'ella non discende; adunque l'acqua di tanto diluvio come si partì, se qui è provato non aver moto? E s'ella si partì, come si mosse, se ella non andava allo in su? E qui mancano le ragioni naturali, onde bisogna per soccorso di tal dubitazione, chiamare il miracolo per aiuto, o dire che tale acqua fu vaporata dal calor del sole."*

(4) Leonardo, Codex Leicester, folio 8v, *del diluvio e de' nichi marini*: "*più oltre si scaricava il fango, nel quale abitava i nichi, il quale s'innalzava a gradi, secondo che le piene d'Arno torbido in quel mare versava, e di tempo in tempo s'inalzava il fondo al mare; il quale a gradi produceva essi nichi, come si mostra nel taglio di Colle Gonzoli, deripato dal fiume d'Arno, che il suo piede consuma, nel qual taglio si vede manifestamente li predetti gradi de'nichi in fango azzureggiante, e*

vi si trova di varie cose marine […] E se li nichi fussino stati portati dal torbido diluvio, essi sarien misti, separatamente l'un da l'altro, infra 'l fango, e non con ordinati gradi, a suoli, come alli nostri tempi si vede."

(5) Leonardo, Codex Leicester, folio 10r: *"E se 'l diluvio predetto li avessi in tali siti dal mare portato, tu troveresti essi nichi in al termine di una sola falda, e non al termine di molte, dove si po annumerare le vernate delli anni […] E se tu volessi dire che più diluvi fussino stati a produrre tali falde, e nichi infra loro, e' bisognierebbe che ancora tu affermassi, ogni anno essere un tal diluvio accaduto."*

(6) Leonardo, Codex Leicester, folio 10r: *"E infra le falde […] e dentro alli termini delle pietre son trovati rari e appaiati di gusci, come quelli che furon lasciati dal mare sotterrati vivi dentro al fango, il qual poi si seccò e col tempo si petrificò."*

(7) Leonardo, Manuscript F, folio 79 and 80: "*Quando li diluvi de' fiumi intorbidati di sottil fango lo scaricavan sopra li animali, che abitan sotto l'acque vicino alli liti marini, essi animali rimaneano improntati da tal fango, era necessario morirsi, mancando loro gli animali, di cui essi nutrire si soleano. E col tempo abassandosi il mare, tal fango, scolate l'acque salse, si venne a convertire in pietra, e li gusci di tali nichi, essendo già consumati li loro animali, erano in loco di quelli riempiuti di fango: e così nelle creazion di tutto il circostante fango in pietra, ancor esso fango, che dentro alle scorze de' nichi alquanto aperto era rimaso, essendo per tale apritura di nichio congiunto coll'altro fango, si venne ancora lui a convertire in pietra*."

(8) Leonardo, Codex Leicester, folio 9r: "*Di quelli che dicano ch'e' nichi sono […] nati remoti dalli mari, […] a costor si risponderà che […] non po accadere […] se non animali di medesima sorte e età, e non il vecchio col giovane, e non alcun col coperchio e l'altro essere colla sua copritura, e non l'uno esser rotto e l'altro intero, e non l'uno ripieno di rena marina e rottame minuto e grosso d'altri nichi dentro alli nichi interi, che li son rimasti*."

(9) Leonardo, Codex Leicester, folio 10r: "*Come nelle falde, infra l'una e l'altra, si trova ancora li andamenti delli lombrici, che camminavano infra esse, quando non era ancora asciutta*."

(10) Leonardo, Codex Leicester, folio 6v: *"Il fiume, che esce de' monti, pone gran quantità di sassi grossi […] i quali sassi sono ancora con parte de' sua angoli e lati; e nel processo del corso conduce pietre minori con angoli più consumati, cioè, le gran pietre fa minori; e più oltre pon ghiaia grossa, e po' minuta […] e così seguendo, giugne al mare l'acqua turba di rena e di lita: la rena scarica sopra de' liti marini […] e segue la lita di tanta sottilità […] e qui stanno i nichi, e quest'è terra bianca da far boccali*."

(11) Leonardo, Codex Leicester, folio 10r: "*Come li fiumi àn tutti segati e divisi li membri delle grand'alpe l'uno dall'altro; e questo si manifesta per lo ordine delle pietre faldate, che, dalla sommità del monte insino al fiume, si vede le corrispondenze delle falde esser così da l'un de' lati del fiume, come dall'altro. Come le pietre faldate de' monti son tutti e' gradi de' fanghi, posati l'un sopra l'altro per le inondazioni de' fiumi. Come le diverse grossezze delle falde delle pietre son create da diverse inondazioni de' fiumi, cioè maggiori ondazioni o minori. Come nelle falde, infra*

l'una e l'altra, si trova ancora li andamenti delli lombrici, che camminavano infra esse, quando non era ancora asciutta. Come tutti li fanghi marini ritengano ancora de' nichi, ed è petrificato il nichio insieme col fango."

[(12)] Leonardo, Codex Atlantic, folio a: "*Li monti son facti dalli corsi de' fiumi; li monti sono disfacti dalle pioggie e dalli fiumi."*

[(13)] Leonardo, Codex Leicester, folio 10v: "*Nel seno Mediterraneo […] le cime dello Appennino stavano in esso mare in forma d'isole, circundate dalle acque salse […] e sopra le pianure della Italia, dove oggi volan li uccelli a torme, solea discorrere i pesci a grande squadre."*