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INTRODUCTION TO QUATERNARY STUDIES IN ITALY: FROM ARDUINO TO THE FIRST HALF OF THE PAST CENTURY

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ABSTRACT: A summary of the origin and development of Quaternary studies in Italy since the 18th to mid 20th century is presented, focussing on marine sediment stratigraphy, continental glacial deposits, vertebrate palaeontology, palaeobotany, and palaeoanthropology. The history of the Quaternary sciences in Italy is also figured in a timeline of main milestones. The presence in Italian Quaternary deposits of cold-water Atlantic immigrants, which currently inhabit boreal seas, was identified by Brocchi in 1814. Following the 18th International Geological Congress (IGC) (1948), there was a surge in interest in these species, resulting in the identification of numerous boreal species (foraminifera, ostracods, bivalves, and gastropods). Even in the second half of the twentieth century, considerable attention was paid to these "northern guests", their systematics, and taxonomic and biostratigraphic revisions, which contributed to defining the species that potentially have a chronological distribution and palaeoecological significance useful for defining Pleistocene marine geochronological stages.
The marine sediments, well exposed in Southern Italy, Sicily and Sardinia, had an important role in the development of Quaternary stratigraphy since Lyell in 1833 introduced the “Newer Pliocene”, later renamed Pleistocene. Several marine stages were defined in Italy, Sicilian by Doderlein in 1872, Calabrian by Gignoux in 1910, Tyrrhenian by Issel in 1914, Milazzian by Deperet in 1918 and other later on. A scientific debate on the Plio-Pleistocene boundary began at the 18th International Geological Congress (IGC) in London (1948) when it was established that it should be placed ”at the horizon of the first indication of climatic deterioration in the Italian Neogene succession” on the base of changes in marine faunas.
The continental deposits, today attributed to the Quaternary, were described and mapped as ’alluvial‘ and ’diluvial terrains‘ until the eighteen seventies. Glacigenic deposits were identified and described in Italy at the foot of the Western Alps by Martins and Gastaldi in 1850 and, in the following decade, at the foot of the Central and Eastern Alps by De Mortillet, Omboni and others. In the last decades of the 19th century, Taramelli, Sacco, and Cozzaglio, began to distinguish the evidence for more than one glaciation. Since the publication of Penck & Brückner’s volumes in 1909, the four-glaciation scheme was generally adopted. The past presence of glaciers on the Apuan Alps and the Apennines was first recognised in the latest 19th century. Subsequently, over a hundred Pleistocene glaciers had been identified and attributed to the Würm glaciation.
The palaeobotanical character of the Quaternary was first recognised by Reboul in 1833, as “characterized by animal and plant species similar to modern living ones at the same site”. Latterly, Brongniart, Sternberg and Balsamo-Crivelli first classified plant macrofossils species, provided timelines and compared finds to the modern extant forms according to the Linnean system. By the end of the 19th century, it became clear that the assemblage of extinct and eradicated plant species in northern Italy gradually decreased through the Pliocene, the Quaternary interglacial and the postglacial periods (Sordelli). The excavating peats at the onset of the 20th century suggested that the macrofossil record could be organised on a robust stratigraphical basis. In 1931-1932, the introduction of palynology in Italy marked the initial development of microbotanical stratigraphy and its application to vegetation, climate history and interactions with prehistoric civilisations.
Since the Renaissance, the remains of Quaternary terrestrial mammals have attracted the attention of collectors and scholars when the collection of fossils from the Upper Valdarno was stimulated by Ferdinando I de’ Medici and Andrea Cesalpino reporting the finding of elephant bones at San Giovanni Valdarno. By the end of the 18th and beginning of the 19th centuries, several new species were identified from the mammalian remains primarily found in the Tuscany basins. Various geologists and naturalists contributed to the knowledge of the Pleistocene deposits and their mammal fossil record in northern, central (e.g. in the Roman Basin), and southern Italy, as well as in Sicily and Sardinia, from where a number of new endemic species were discovered. In 1865 Pareto proposed the Villafranchian Stage for the sequence of fluvial and lacustrine sediments of Villafranca d’Asti (Piedmont). The comparison of the mammalian fauna of Villafranca with that of other Late Pliocene-Early Pleistocene faunal assemblages from Italy, led successively to the definition of the ‘Villafranchian European Land Mammal Age‘.
Lastly, a brief outline of the beginnings of palaeoanthropological research and the noteworthy Palaeolithic human remains discovered in Italy until the first half of the 20th century is given.

Keywords: stratigraphy; glaciations; vertebrate palaeontology; palaeobotany; palaeoanthropology; history of science.

1. FOREWORD

Italy possesses a rich and diverse variety of geological, palaeobiological and archaeological archives from the Quaternary. The studies undertaken in Italy have provided important contributions to the recognition of the peculiar characters of the Quaternary, i.e the climate and the connected environmental changes that led to the glacial-interglacial cycles, the evolution of palaeoenvironments and mammalian communities, as well as the diffusion and settlements of prehistoric human populations in the country.

Here we summarise the first studies on marine sediments in relation to stratigraphy and palaeoclimatology, the continental deposits since the dawn of the 'glacial theory', and the fossil continental mammal faunas and plants. We also note the earliest research in palaeoethnology as well as the discovery of Palaeolithic human remains. We focus on the period from the 18th century to the mid-20th century, before the revolution in Quaternary stratigraphy and palaeoclimatology began by Cesare Emiliani (1955, Fig. 1d, see section 2.3) with the isotopic studies of deep-sea cores, at the time of the IV INQUA Congress held in Rome-Pisa (1953) and the first international scientific journal entirely dedicated to Quaternary, *Quaternaria*, published in Rome in 1954 by Alberto C. Blanc (Fig. 1c).

An introduction to Quaternary studies in Italy can ideally start with one of the fathers of the stratigraphy, the Veronese Giovanni Arduino, "the man who invented the Quaternary" (Gibbard, 2019). In a letter addressed to Antonio Vallisnieri, professor of Natural History at the University of Padua, written in 1759 and published in Venice in 1760, Arduino [(1)] wrote: 'As far as I observed up to now, the sequence of strata composing the visible bark of the Earth seems to me to be distinct in four general and subsequent orders. The four orders may be considered as four huge strata …placed on top of each other …each of them made by countless other minor strata, composed of materials of many different types'. The four orders clearly show 'to have been formed not only in different times but also under very different conditions'. 'The first order, the deepest, and the second, following the first, form the great mountains, the third forms small mountains and hills, while the fourth forms the plains … also formed by beds over beds, by floods with deposition of materials carried down the mountains by waters of rivers and streams, reduced …to pebbles, gravel, sand and mud'.

Arduino (1760, Fig. 1a) used the terms *primary*, *secondary* and *tertiary* as adjectives, respectively for the first, second and third order but he did not mention the term *quaternary*

for the fourth order. Probably since that time this word remained about to happen. The term *Quaternaire* was first informally ("*pour ainsi dire"*) used by Desnoyers (1829, p. 193) to designate the marine deposits "*plus récens* (sic) *que les terrains tertiaires du bassin de la Seine",* but he denounced usage of this word in a footnote on the same page. The name *Quaternaire* was succesively applied by de Serre (1830) and "finally defined on palaeontological grounds in 1833 by H. Reboul" (Head & Gibbard, 2015). He wrote: "*Les monuments fossils des terrains tertiaries appartiennent presque tous à des espèces perdues. . . . C'est-pourquoi on a dû appeller quaternaire la période subséquente, dont les terrains sont caractérisés par des espèces animals et végétales, semblables aux êtres actuellement vivans dans les mêmes lieux*" (Reboul, 1833).

In the same period (1828-1829) Charles Lyell (Fig. 1a) was visiting Italy from Piedmont to Sicily "in order to acquire more information concerning the tertiary formations", having "already conceived the idea of classing the different tertiary group, by reference to the proportional number of recent species found fossil in each" (Lyell, 1833). He examined the collections of "tertiary shells" collected by some Italian palaeomalacologists (F.A. Bonelli, G.B. Guidotti, O.G. Costa) in Piedmont, the "Subappennine" (Parma) and southern Italy in Turin, Parma and Naples, and compared them with living species of the Mediterranean. Lyell himself examined many localities in southern Italy (Ischia, the flanks of Mount Etna and Val di Noto), collecting fossil shells. His investigations led him to conclude with "most lively surprise" that the majority of the fossil species collected "even at the height of 2000 feet above the level of the sea" were "species now inhabiting the Mediterranean" (Lyell, 1833). Lyell, proposing a subdivision of "the great tertiary epoch" attributed the beds of Ischia and Val di Noto to the fourth and youngest subdivision, named "Newer Pliocene", that was renamed "Pleistocene" a few years later (Lyell, 1839, Fig. 1a). The marine Pleistocene of Italy was later studied by many Italian and foreign scientists, assuming great relevance for the Quaternary stratigraphy.

Despite the Arduino's early hesitation, the term Quaternary was introduced relatively late in Italy. The continental deposits currently attributed to the Quaternary, were, until the second half of the 19th century, generally named *"Terreni di trasporto antico e recente*" or "*Alluvioni antiche e moderne*" (ancient and recent transport/alluvial deposits) or with the Latin names *Diluvium* and *Alluvium,* respectively. The term Quaternary was used with differing meanings. Among the first Italian essays on stratigraphy, Pilla (1845) distinguished, in the deposits above the 'Tertiary terrain', from top downwards, the 'Recent (or Modern) terrain' and the 'Ancient alluvial terrain (*Diluvium* and Erratic boulders)' The Modern terrain was subdivided into lacustrine, marine and 'quaternary terrain (emerged beaches)'. Later Pilla (1847-51) specified in a textbook that he defined 'Formation…. a rock or a union of strata produced in a narrow period of time' and 'Terrain…. a union of for-

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[1] The original sentences reproduced from previous authors are quoted in single quotation marks '…', if literally translated from the Italian, in double quotation marks "…" in roman type, if in English, in italics if in other languages.

mations showing features of chronological similarity'. He further stated that he included the 'raised beaches or post-pliocene of Lyell' as quaternary terrain. Pareto (1846b) named 'quaternary … the most recent among the sedimentary terrains …to distinguish it from the subappenine tertiary formation'. In one of the first Italian geology textbooks (*Elementi di Geologia Pratica e Teorica*), Collegno (1847) incidentally mentioned that recently the 'transport terraines have been named as Quaternary terrains by a few modern geologists'. Scarabelli (1852, Fig. 1a) described the Quaternary deposits (also called Apennine *diluvium*) of the Imola region, as a sequence of gravel, silt and sands with fossils of *Rhinoceros*, other pachyderms and continental molluscs, unconformably overlying the marine Pliocene. De La Marmora (1857) devoted an entire chapter of his book ("*Voyage en Sardaigne"*, part 3: Geological description) to the "*Terrains Quaternaires"*. He included in his "*Terrains Quaternaires*" the "*Grés quaternaire*" (Quaternary sandstone) with marine shells, unconformably overlying Pliocene marls or on bedrock, the raised beaches, the bone breccia, the *Diluvium*, the recent alluvial deposits, the barrier beaches. Stoppani (1873), in his *Corso di Geologia - vol. 2 Geologia stratigrafica* proposed that the Cenozoic Era should be followed by the Neozoic Era (Post-tertiary or *Quaternary*), in turn followed by the Anthropozoic Era. Subsequently in a textbook on Geology, Curioni (1877) asserted: 'Many geologists subdivide the terrain that was formed after the new Pliocene into three epochs, i.e: the epoch of the ancient *alluvium,* the epoch of the *diluvium*, the glacial epoch. This complex of deposits is said *quaternary*.'

The *Carta geologica della Liguria marittima* by Pareto (1846a, Fig. 1a), the *Carta Geologica della Provincia di Bologna* (Scarabelli, 1853), the *Carta Geologica della Provincia di Ravenna* by Scarabelli (1854, Fig. 1a), the *Carte Géologique de l'Ile de Sardaigne* by de La Marmora (1856), the Lugano-Como 1873 geologic map 1:100.000 by Spreafico, Negri and Stoppani (1873), are among the first geological maps to adopt the term Quaternary in Italy (generally as a synonym for *Diluvium*). However, the terms *Alluvium* and *Diluvium* (and equivalents) were still in use until the eighteen seventies on most maps. The term Quaternary started to be used in the Italian official geological maps since the first edition of the *Carta Geologica d'Italia* at the scale 1:1,111,111 (1881) and of the first geological maps at the scale 1:100,000, published in Rome (1884). On these maps, two stratigraphic units were distinguished above the Pliocene: *Quaternario* (Quaternary) and *Recente* (Recent). Beginning from the second edition of the *Carta Geologica d'Italia* at the scale 1: 1,000,000 (1889), the *Quaternario* has been subdivided into *antico ("Plistocene")* (sic) and *Recente.* The Quaternary, subdivided in Pleistocene and Holocene, appeared in the legend of the official geological maps of Italy 1:100,000 since the 1920s. A comprehensive overview of the history of the cartographic production by the Servizio Geologico d'Italia is presented by Console et al. (2017).

2. THE DAWN OF QUATERNARY MARINE GEOCHRONOLOGY AND CHRONOSTRATIGRAPHY IN ITALY

The Mediterranean region, with its long, tectonically undisturbed, and well-exposed stratigraphic Neogene sequences, has played a pivotal role in the development of Quaternary stratigraphy since the beginning of geological research. In particular, along the coasts of southern Italy and Sicily, marine sediments have been uplifted by several tens of metres over the last three million years. The abundance of hemipelagic sediments favours deconstructing, for instance, the microfaunal and nannofloral evolution, the chronological assessment of species and the palaeoenvironmental development through time.

2.1. The "northern guest" immigrants in marine faunas

The presence in Italian Quaternary deposits of cold -water Atlantic immigrants, which currently inhabit boreal seas, was proposed by Brocchi in 1814 on the basis of an erroneous attribution to "*Venus islandica*" of some *Sinodia* shells. It was later correctly reported for the first time by Philippi (1834-1836), who identified some species of boreal molluscs in the Quaternary deposits of Sicily. Following the 18th IGC (1948), there was a surge in interest in these species, resulting in the identification of numerous boreal species in other groups (foraminifera, ostracods, bivalves and gastropods). Even in the second half of the twentieth century, considerable attention was paid to these "northern guests", their systematics, and taxonomic and biostratigraphic revisions (e.g., Malatesta & Zarlenga, 1986; Pasini & Colalongo, 1997; Faranda & Gliozzi, 2011; Gibbard & Head, 2010, and references therein). This contributed to defining the species that potentially have a chronological distribution and palaeoecological significance which is valuable in defining Pleistocene marine geochronological stages.

2.2. The marine stages proposed before the 1960s

In the beginning, the proposal and definition of marine stages were primarily based on palaeontological criteria (particularly bivalves and gastropods, as well as corals, ostracods and benthic foraminifera), and later, particularly but not exclusively, on planktonic foraminifera and calcareous nannofossils. In recent years, palaeomagnetic evidence, absolute dating, and palaeoclimatic and proxy studies have all played an increasing role in marine chronostratigraphy and geochronology.

The Sicilian, the first stage to be proposed during the 19th century, is one of the best defined among the divisions. Doderlein (1872) described the Sicilian as a Pliocene stage typified as "*par le calcaire à coquilles tertiaires des environs de Palerme, Bagheria et de la baie de Ficarazzi et par le mélange de calcaire pliocène et de laves qui constituent le sous-sol de la plaine de Catane*".

The palaeontological characteristics of the Sicilian fossiliferous levels emphasised by Doderlein (particularly the increase of "northern guests") correspond to those cited later by De Sfefani (1891b) as typical of the level intermediate between the first and third of the three stratigraphic levels into which the italian palaeontologist divides his "post-Pliocene." De Stefani (1876), indeed, distinguished a post-Lower Pliocene, whose malacofauna still had affinities with the Pliocene, and a post-Middle Pliocene characterised by an increase in "northern guests" and a decrease in survivors of the Pliocene. In the post-Upper Pliocene, the latter characteristics became more pronounced, and modern species also proliferated.

The well-known Calabrian Stage was introduced into the scientific literature by Gignoux (1910), who considered that it was deposited after the Pliocene. He designated the section of S. Maria di Catanzaro as the reference locality, where the base of the new stage was placed. Gignoux (1913) observed: "*Au Monte S. Maria, le plateau culminant du point 207 est occupé par des marnes blanches qui recouvrent le banc à Cyprina islandica" (*recte *Arctica islandica)*. The French scholar also underlined that the deposition of such a level reflected a variation in the sedimentation accompanied by a change in the benthic community, while no discontinuities arising from flooding were present. Therefore, he concluded that during the Calabrian, a pre-existing clayey facies persisted, and this continuity of sedimentation related the early Pliocene to the Calabrian. As a result, according to Gignoux (1910, 1913), the Calabrian would correspond to the post-Pliocene of De Stefani (1891b), characterised by the appearance of molluscs of boreal origin (i.e., *Artica islandica*) in the Mediterranean Sea.

Decades after Gignoux's publications, micropalaeontological analyses at Santa Maria di Catanzaro have demonstrated that, *Hyalinea baltica* and *Globorotalia truncatulinoides excelsa* were present in the same bed where *A. islandica* first appears (Sprovieri et al., 1973; Colalongo & Pasini, 1980; Colalongo et al., 1980, 1981, 1982). As a result, Gignoux's 'Calabrian' deposits are actually transgressive on the underlying Pliocene marls, the latter referable to Doderlein's (1872) Sicilian Stage, as are several sections described by the same author (e.g., Caraffa, Monasterace, Palermo).

Subsequently, the chronostratigraphical significance and rank of the Calabrian Stage were reconsidered several times in the competition among the various Pleistocene and Pliocene sections exposed in southern Italy (Cita et al., 2008). This continued until its formal definition in 2012 as the second stage of the Pleistocene Series and Quaternary System, following the Gelasian (Global Boundary Stratotype Section and Point, GSSP, at Vrica, Calabria) (Cita et al., 2012). Furthermore, the evidence of a biostratigraphical correlation between the stratotype of this stage and the G-G level at Santa Maria di Catanzaro, and thus the priority of the Sicilian name over the Calabrian, demonstrated that the subdivision of the lower Pleistocene into Calabrian and Sicilian (Gignoux, 1913) or into Calabrian, Emilian and Sicilian (Ruggieri & Selli, 1950) (see below) can no longer be accepted.

The Tyrrhenian Stage, recommended in 1914 by Issel (Fig. 1b), is one of the stage names, proposed at the beginning of the 20th century, that is still widely used in the scientific literature, albeit with different chronostratigraphical connotations. Indeed, a formal definition of the Tyrrhenian Stage has never been proposed and indeed no potential subdivision of the Upper Pleistocene (following the formally defined Middle Pleistocene Chibanian Stage) has thus far been approved. The definition of stage/age and Global Stratotype Section and Point (GSSP) of the Upper Pleistocene Subseries/ Subepoch is indeed still pending.

Issel (1914) based the establishment of the new Tyrrhenian Stage (originally called "Tirreno") on the study of the rich marine fauna, characterised by the presence of 'tropical' taxa and those preferring warm waters, present in the coastal marine deposits of the stratigraphic succession still exposed at Cala Mosca (Is Mesas, Capo Sant'Elia, Gulf of Cagliari). Following Issel (1914), all the deposits subsequent to the Sicilian of Doderlein and prior to the Holocene (which at the time still remained poorly defined) could be referred to the Tyrrhenian. Accordingly, the "Tirreno" in its original concept would include the entire Upper Pleistocene.

The Cala Mosca levels were deposited during a high sea-level stand phase. Consequently, the name Tyrrhenian has generally been used to indicate marine deposits of the Last Interglacial. Despite this, following Issel (1914), the "Tirreno" stage would cover a much longer time period, spanning from the warmest phase of the Late Pleistocene, documented by the presence of "*Strombus bubonius*" (recte *Thetystrombus latus*, Fig. 1b), to the last glacial stage. Later, Bonifay & Mars (1959) assigned the typical "*Strombus bubonius*" faunal peak to their newly proposed chronostratigraphic subunit of the Tyrrhenian, the Eutyrrhenian, choosing the Cala Mosca beach deposit as the stratotype. Coastal deposits at a height corresponding to the highest last interglacial sea-level stand would represent the Eutyrrhenian subunit. This led to the correlation between the Eutyrrhenian and Marine Isotopic Substage 5.e.

Depéret proposed the Milazzian Stage in 1918, based on the rich mollusc fauna discovered in the pebbly sandy levels exposed along the western coast of Capo Milazzo (north-eastern Sicily). In contrast to the other stages already mentioned, the Milazzian was used mostly before the 1970s and has now generally fallen out of use. According to Depéret (1918), the Milazzian would have spanned a temperate time interval, with the corresponding level characterised by a banal malacofauna similar to that found today in the Mediterranean. Gignoux (1913) had already reported the presence of such a mollusc association that differs from the 'cold' one of the Sicilian deposits and that of the Tyrrhenian "*Strombus* levels". A similar fauna was found at Capo Milazzo in marine terraced deposits which are located about 50-60 m above sea level (Ruggieri & Greco, 1965). This altitude is intermediate between the height of the Sicilian deposits of Gignoux (1913) (100 m) and that of the "Tyrrhenian" levels with "*Strombus bubonius*" and the Senegalese molluscs of Issel (1914). The Milazzian Stage, indeed, was not a well-founded division, several scholars having questioned its validity. For example, Ottman & Picard (1954) noted that the presence of *Patella ferruginea* and *Luria lurida* in the Milazzian deposits, which entered the Mediterranean basin during the "Tyrrhenian," suggests a more recent age (Last Interglacial) for the levels of the Capo Milazzo terrace, which was tectonically disturbed and uplifted, as already hypothesised by Molino Foti (1869). The attribution to MIS 5e was made possible later by absolute dates on *Glycymeris* sp. (Amino Acid Racemization dating to c. 120 ka) and on a calcareous algae nodule (U-series dating: 83-100 ka) (Belluomini, 1985; Hearty et al., 1986).

During the London IGC (1948), Ruggieri & Selli (1949, 1950) introduced a new stage (Emilian or Calabrian II/"Hot Upper Calabrian"), chronologically interposed between the Calabrian and the Sicilian. Studies of Plio-Pleistocene sequences exposed in the Emilia region revealed deposits of a warm-temperate fauna. Both Selli and Ruggieri (Ruggieri, 1954,1957; Selli, 1967,1973) confirmed the original definition of the Emilian, pointing out its climatic character and hypothesising a correlation with the 'Gunz-Mindel' interglacial. Following the Italian researchers, the Emilian stratotype had to be defined in the Santerno river valley where a long Pliocene-Pleistocene marine sequence, characterized by the appearance progression of boreal species (*A. islandica, H. baltica*, and *G. truncatulinoides excelsa*), is well exposed between the villages of Tossignano and Imola (Bologna). Later, Ruggieri et al. (1977) highlighted the presence of many temperate episodes in several Pleistocene sequences in Italy. Such evidence suggests that the Emilian cannot be distinguished by a single temperate climate criterion. Accordingly, the new definition of the Emilian Stage was based on biostratigraphical criteria, i.e., *H. baltica* FAD in the Santerno section level, the site already proposed as the Emilian stratotype.

For an updated state of the art on Global Boundary Stratotype and Points (GSSPs) in the Quaternary system, based on the stratigraphic record of Italy, consult Capraro & Maiorano (2023, this volume).

2.3. The emergence of marine isotopic stratigraphy

In the 1950s, the Italian-American geologist Cesare Emiliani (Fig. 1d) significantly advanced knowledge on marine stages by applying the Urey's isotopical analytic method to calcareous foraminifers. He observed that in the shells the ratio between ^{18}O and ^{16}O ($\delta^{18}O$) periodically varied by about 0.2% and related such a variation to ocean temperature fluctuations. He correlated the palaeotemperature fluctuations deduced from isotopic data with glacial and interglacial phases (Emiliani, 1955), introducing the numbering of the 'marine isotope stages' which is still used today, although with several refinements (see Railsback et al., 2015, for further details). Soon after, Emiliani embarked on the study of isotope stratigraphy of marine section La Castella in S-Italy, which was committed for research on earliest cold spells in search for the Plio-Quaternary boundary (see section 2.4). Emiliani's fundamental studies laid the groundwork for the development of marine isotope stratigraphy.

During the second half of the 20th century to recent times, multidisciplinary studies of the well known Italian long stratigraphical sequences led to the revision of already defined Pleistocene marine stages, as well as to proposals of new divisions (cf. Head, 2019), confirming the crucial role of Italian deposits in the development of Quaternary marine chronostratigraphy.

2.4. The first proposals for the Plio-Pleistocene boundary

Although being the first boundary to be examined by taking into account the stratotype concept, the question of the boundary between the Pliocene and the Pleistocene was not officially debated until many years after the pioneering research of the 19th century.

The criteria for the definition of the Plio-Pleistocene boundary were first discussed in 1948, during the 18th IGC in London. It was established that the boundary should be placed «at the horizon of the first indication of climatic deterioration in the Italian Neogene succession and should be based on changes in marine faunas». Four years later, during the XIX IGC, Alger 1952, the Plio-Pleistocene boundary was confirmed in the four Italian stratigraphical sections exposed at Monte Mario, near Rome (Blanc et al.,1954), Castell'Arquato (Piacenza) (Di Napoli Alliata, 1954), Santerno (Imola) (Ruggieri, 1954), and Val Musone (Ancona) (Selli, 1954).

Later, during VI IGC (1961, Warsaw, Poland) and VII of the XIX IGCs (1965, Denver, Colorado, USA), it was decided that the boundary had to be placed in the Le Castella section (Crotone-Spartivento, Calabria), at the base of the sandy level (G-G1) characterised by the first appearance (FAD) of the benthic foraminiferan *Hyalinea baltica* (Emiliani et al., 1961).

3. CONTINENTAL QUATERNARY DEPOSITS

Among the large variety of continental deposits, this chapter mainly concerns the glacigenic materials, since they have gradually assumed significant importance in the Quaternary terrestrial stratigraphy of the country.

3.1. The advent of the glacial theory and the Ice Age

As already mentioned, the continental deposits in Italy today attributed to the Quaternary, after Arduino and for the most part of the 19th century, were described as alluvial and diluvial deposits. The latter were originally thought to have resulted from the Noachian flood, and were later attributed to a variety of origins. In northern Italy the large alluvial plain of the Po Valley drew the attention of the first geologists. Breislak (1822) recognised that the plain, in the province of Milan, was entirely composed of 'alluvial or transport terrain' at every depth where it could be observed. He just made a lithological distinction between pebbles and erratic boulders, gravels and sands, clays, calcareous tufa, peats, etc. Moreover, he believed that the erratic boulders were transported by icebergs delivered by the alpine glaciers into the sea, an idea widespread at his time. Venturi

(1817), the physicist known for the 'Venturi effect' in fluid dynamics, calculated the volume of a block of ice necessary to float, supporting the pedestal of the 'Bronze Horseman', the equestrian statue of Peter the Great in St. Petersburg. The pedestal was made from a giant boulder of Rapakivi granite, half embedded in a marshy ground near the city. Venturi concluded that in the past the large glaciers of the Alps could have produced 'pieces of ice swimming on the sea', with a volume sufficient to carry very large boulders.

Catullo (1838), describing the Venetian provinces, made a distinction between 'alluvial terrains (deposits even now forming in any part of the Earth)' and the 'more extended and higher diluvial terrains (deposits that look like formed by the same waters responsible of the tertiary deposits)'.

Continuing this theme, Curioni (1844), in a review on the geology of Lombardy, mentioned 'the erratic formation, scattered on the back of the mountains, largely accumulated on the hills and more widely on all the Po plain'. The large boulders of alpine rocks, lying at a great distance from their origin in the high mountains, beyond deep lakes, aroused the most passionate investigations. At first it was imagined that they were carried here and there on an ancient ocean on floating ice. De Buch and De Beaumont thought they were dragged by the violence of enormous water currents, whilst the Swiss geologists Charpentier, Venetz, Agassiz recognised in them 'the progressive motion, over vast regions, of glaciers pushing forward loose rocks and piling up them to form large dams or moraines'. Collegno (1847) defined the 'alluvial terrains' as 'deposits formed by present causes with the same energy of today', while the 'diluvial terrains were formed by the same present-day processes, but temporarily powered by a much higher and presently unknown strength. These anomalous deposits were also named *erratic terrains,* to mean materials transported by agents at present no longer active or too weak where now we can see them'. Although Collegno was aware of the *glacial theory* developed in the Alps by Jean-Pierre Perraudin, Ignaz Venetz and Jean de Charpentier in the first decades of the 19th century, and dramatically illustrated by Agassiz in his volume *Études sur les glaciers* (1840), he continued to support the idea that the erratic blocks were transported by ice rafts. In fact, although the *glacial theory* was rapidly accepted by Buckland and Lyell, many geologists remained unconvinced for many more years.

As De Mortillet (1861) mentioned, in the decade following the publication of the Agassiz's book, several Italian and foreign students (Leblanc, Carrel, Gal, Guyot, Forbes, Coulomb, Studer, Zollikofer, Martins, Villa, Catullo, Parolini) observed and described erosional and depositional features on the southern side of the Alps and on their foothills that they interpreted as the evidence of the past presence of glaciers. The first truly important paper, 'that opened the study of glacial phenomena in Italy' (Taramelli 1903) was that by Martins and Gastaldi (1850, Fig. 1a) on the "*terrains superficiels de la vallèe du Pô, aux environs de Turin, comparés à ceux de la plaine Suisse*". These authors fully accepted the 'glacial theory', correctly recognising the geological evidence for the glacial erosion, transport and deposition. Among the glacial-erosional forms they described are: polished and striated rocks with glacial striae and grooves ("*roches polies, striées et cannellées"*), different systems of striae indicating successive stages of glacier extent with different flow directions, "*roches moutonnées*" with asymmetric (stoss and lee) long profiles (indicating the direction and versus of glacier flow), striated pebbles and blocks ("*cailloux rayés"*). The accumulation forms and glacial deposits described include: terminal moraines ("*moraines latérales, moraines frontales"*), ground moraine ("*moraines profondes"*) with hummocky topography, supraglacial and subglacial debris, lodgement and ablation till ("*moraine superficielle")*, aligned erratic blocks on the valley sides, together indicating the past glacier limit. In addition, Martins & Gastaldi (1850) recognized that the size of the lateral moraines was related to the height of ice-free valley slopes and to the size of the drainage basin, as well as the fact that the debris lithology was indicative of the rocks outcropping on the side of the valley.

They first described the past presence of glaciers in the Dora Riparia and Dora Baltea basins, the ice having flowed along the Susa and the Aosta valleys, expanding and terminating on the Po Plain with two piedmont glaciers that formed, respectively, the terminal moraine systems (defined as *morainic amphitheatres*) of Rivoli and Ivrea. They clearly distinguisheded a sequence of almost circular concentric moraines separated by small lakes or peat bogs, that represent the maximum advance and the recessional stages of the glacier. The high terminal moraine of the Dora Baltea glacier, named *la Serra,* was described as a 'huge rampart with steep sides, particularly the inner one, projecting itself on the sky as a straight line lowering as it advances in the plain'. Since then *la Serra* has been considered one of the best preserved examples of a end moraine left by past glaciers in Italy. Martins & Gastaldi (1850) also interpreted the *alpine diluvium* as glaciofluvial (outwash) deposits, describing their relatiosnship with the glacial deposits: 'when a glacier advances, it builds new end moraines on the *diluvium*…. when it melts down and retreats it abandons on the *diluvium* ground and ablation moraines'.

In the following years many studies were devoted to the glacial deposits in Italy. For example, Villa (1857) recognised that 'all the hills branching out from Erbusco towards Calino and Torbiato to Iseo represent the various terminal moraines left by a large glacier descending by the mountains beyond Lake Iseo', as described with further details and represented in a sketch-map by de Mortillet (1859). Latterly, Omboni (1861a, Fig. 1b) described and mapped the concentric semi-circular hills just south of Lake Orta and Lake Maggiore as ancient moraines and attributed them to ancient glaciers of the Ticino and Toce valleys.

In a short note, at much the same time, Paglia (1861, Fig. 1b) recognised the elongated hills, with a triangular section, made of 'erratic terrain', and forming concentric semi-circular alignments south of Lake Garda, as possible terminal moraines. He clearly mapped the more external arched moraine extending from Calcinato to Castenedolo from the group of younger moraines between Castiglione dello Stiviere and the Oglio River. Further to the East, where the Tagliamento river flows from the Carnic Alps into the plain, Pirona (1861, Fig. 1b) described a sequence of concentric hills comprising 'pebbles of various size, many of them striated, mixed with gravel, sand and clay, with any sign of lacustrine or fluvial stratification. At the surface of the hills, here and there large angular blocks made of various rock types are scattered'. He concluded that all these hills were terminal moraines produced by a huge ancient glacier that flowed from the Carnic Alps.

De Mortillet (1861) compiled a map of the ancient glaciers on the Italian sides of the Alps, shortly describing, from west to east, all the drainage basins that hosted large valley glaciers, many of them flowing into the plain and forming piedmont lobes. These last are documented by the morainic amphitheatres of Rivoli, Ivrea, those south of lakes Orta, Maggiore, Lugano, Como, Iseo, Garda, and those of Piave and the Tagliamento rivers. Omboni (1861b), after a statement in favour of uniformitarianism ('geologists have now adopted the method of studying the present phenomena to explain those happened in the past'), described the geological evidence left by glaciers in the present basins of the Ticino, Adda and Oglio rivers, including the great lakes at the foot of the central Alps. He paid particular attention to the lithology of the erratic blocks, reconstructing the provenance of the different valley glaciers. He distinguished the glacier of the Toce basin, branching towards the present Lake Orta and Lake Maggiore valleys, the glacier of the Ticino basin flowing along the Lake Maggiore and western Lake Lugano valleys, and the Liro and Mera basins glacier merging with the Adda basin glacier and flowing with several interconnected branches along the valleys today occupied by the lakes Lugano, Como and Lecco. All these glaciers reached the northern margin of the river Po plain where, at the foot of the Alps, where they formed a complex set of coalescent piedmont lobes. A sketch-map showing the geographical distribution of seven different groups of lithotypes present in the glacial deposits of Lombardy was a first example of a study of provenance of the glacial sediments.

In the second half of the 19th century, the studies on the 'glacial period' by Abbot Antonio Stoppani (1867, 1873, 1880, Fig. 1b) had particular influence in Italy. In 1873, Stoppani published the textbook on stratigraphy mentioned in the Foreward and, few years later, a book on the Ice Age in Italy (Stoppani, 1880, *L'Era Neozoica*). He considered the Ice Age as one single glacial interval immediately following the deposition of the Pliocene marine beds, when the Pliocene sea was still present in the Po valley at the foot of the Alps. As depicted on the cover of the book, he imagined the Alpine glaciers descending into fjords, where they released icebergs, while reindeer, bears, marmots and pachyderms inhabited the ice-free areas. This idea was based on the discovery (a few years earlier) of glacial deposits containing Pliocene marine shells in the Como and Ivrea morainic amphitheatres. He interpreted these deposits as glaciomarine in origin. He considered (and figured in a map) the morainic amphitheatres south of the Alps as directly deposited at the margin of the Pliocene Adriatic gulf of the Mediterranean that covered the entire present Po plain. This hypothesis was discussed and rejected by Sordelli (1875), Omboni (1877) and by Gastaldi, Taramelli and Baretti who considered the fossil remains as reworked Pliocene 'warm' water marine fauna.

3.2. Glacial and interglacial periods

During the last three decades of the 19th century new more detailed studies were undertaken on the glacigenic deposits of northern Italy by Taramelli, Sacco, Cozzaglio and Stella. They initially recognised deposits of 2 - 3 discrete successive glaciations. Taramelli (1870, 1875, 1881) mapped and described the glacial deposits of Friuli, including the Tagliamento piedmont glacier system, and in 1903 he published a geological map of the Prealps and of Lake Maggiore, Lake Lugano and Lake Como morainic amphitheatres. These features occur between the Ticino and Adda rivers, where they represent three successive glaciations. In his map he distinguished: 1) post-glacial alluvial deposits, 2) fluvioglacial (recent *Diluvium*) and glacial deposits of the last glaciation, 3) weathered fluvio-glacial and glacial deposits (middle *Diluvium* locally glacial), deeply weathered fluvio-glacial and glacial deposits (ancient *Diluvium* locally glacial), together indicative of three glaciations. Subsequently, Sacco mapped and described the morainic amphitheatres of Rivoli, Lake Maggiore, Lake Como, Lake Iseo, Lake Garda and those of the Veneto region, in a sequence of publications between 1886 and 1898. In these articles he failed to distinguishing moraines of the different glaciations but he did recognise three orders of terraces. Shortly afterwards, Cozzaglio (1891,1902) studied the morainic amphitheatres of Lake Garda and Lake Iseo.

Stella (1895) summarised the knowledge obtained by Sacco, Taramelli, Cozzaglio and himself from the surveys made for the Geological map of Italy 1:100,000.They clearly distinguished between the post-glacial fluvial deposits (*Alluvium*) from the older Quaternary deposits (*Diluvium*) on the base of palaeontological and hydrographical-morphological characters. In turn, the *Diluvium* was divided into three units (three terraces), the recent, the middle and the ancient *Diluvium*. This was based on the basis of topography, morphology, weathering and stratigraphical relationships of the units. The recent *Diluvium* forms the lower outwash terrace and is connected to the well-preserved moraines of the amphitheatres; the deeply weathered and rubefied ancient *Diluvium*, forms the remnants of the highest terrace with a gently undulating surface and locally including glacial *facies*; the middle *Diluvium* forms the remnants of the interposed, weathered terrace, and instead was interpreted as representing an interglacial accumulation.

The short paper by Penck et al. (1894, Fig. 1b) "*Le system glaciaire des Alps*", that anticipated the classic Penck & Brückner (1909) synthesis, led the way to new studies on the alpine glaciations also in Italy. The article clearly described and figured the internal structure and surface appearance of the Alpine glacial depositional systems, demonstrating the distinction between the glacial and fluvioglacial formations and their "*relation intimes*". The main criteria to distinguish the deposits of successive glaciations were summarised as: the degree of surface weathering (including mention of the *ferretto* of Lombardy, see below), the presence and number of loess/lehm strata and the morpho-stratigraphical relationships of the deposits (*superposition versus emboîtement*). On the basis of these criteria 'it was necessary to admit that the three morphostratigraphic units (*Deckenschotter, Hochterrassenschotter* and *Niederterrassenschotter*) and their moraines were indicative of three successive glaciations'.

For the Quaternary studies, the 20th century opened with *Die Alpen im Eiszeitalter*, the three volume compendium by Penck & Brückner (1909) summarised their research lasting decades, that became the paradigm in glacial geology for the next 50 years. Based on the morphological evidence in the Alpine foothills, the authors described a glacial system composed of three major elements: a basin left by a glacier tongue, a belt of enclosing terminal moraines and an outwash fan and plain complex external to the moraines (Fiebig & Preusser, 2008). Indeed, they recognised four stacked main outwash terraces, each connected to glacial deposits, attributed to four successive glaciations (termed Günz, Mindel, Riss, Würm), separated by interglacial periods during which the previous deposits were incised and weathered under warm/mild climatic conditions.

The largest part of Penck & Brückner's third volume is dedicated to the Italian Quaternary glacial deposits from the Piedmont to the Friuli-Venezia Giulia region. The largest morainic amphitheatres are described with the differentiation (in the sections and maps) of three main units: *Jungmoränen* (W), *Altmoränen* (R), *Ferrettomoränen* (Mf) and their related outwash terraces. In the Ivrea morainic amphitheatre, a section across the large composite 'La Serra' moraine, shows the innermost part attributed to Würm, the largest part to Riss, while at the outmost border buried glacial deposits are attributed to the Mindel. In the Lake Maggiore and Lake Como, Würm, Riss and Ferretto/Mindel amphitheatres moraines with their outwash terraces are clearly identified. The *ferretto* is the deeply weathered topmost part of the fluvioglacial and glacial deposits attributed to the Mindel-age glaciation, developed during the (supposed) long Mindel/Riss interglacial. Locally evidence of more *ferretto* surfaces of different ages were also observed. In contrast, in the Garda amphitheatre only the most external moraine on the west side was attributed to the Riss, and all the other moraines to the Würm, while in sections along the bank of Chiese River glacial and fluvioglacial deposits were assigned to the Mindel and Günz glaciations.

The influence of Penck & Brückner's work on the Italian studies in the following decades remained substantial. On the official geological map 1:100,000, Sheet Ivrea, mapped by Franchi, Mattirolo, Novarese and Stella (1912) in 1890-1910, two glaciogenic units are distinguished in the Ivrea morainic amphitheatre: 1- Würmian moraines, connected to the recent Diluvium outwash terrace and 2- weathered ancient moraines (pre-Würmian), connected to the weathered ancient Diluvium outwash terraces ("*ferretto*"). On the Aosta Sheet, surveyed by Mattirolo et al. (1912), the glacial deposits are indicated as Würmian, post-Würmian and recent moraines.

Sacco (1919) accepted the four glaciations scheme and in 1927 recognised three glaciations in the Ivrea morainic amphitheatre, equating them to the last three of Penck & Brückner. Likewise, Cozzaglio (1933) adopted the four-fold glaciation scheme for the Garda morainic amphitheatre, accepting the stratigraphical evidence for the Günz glaciation along the Chiese River, albeit attributing the most external moraine on the west side to the Mindel while recognising an outer part attributed to the Riss and an inner part attributed to the Würm glaciation in the rest of the amphitheatre. Glacial and glacio-lacustrine deposits attributed to the Günz glaciation were reported by Nangeroni (1929, 1950) and by Riva (1942) in Lombardy.

Haupt (1938) studied the glaciation in the Bergamasque Alps with a detailed map of the extent of the ice cover. A beautiful colour map of the extent of the last glaciation in the Italian Alps (and the Northern Apennines) was drawn by Bruno Castiglioni (1940).

3.3 - The full acceptance of Penck & Brückner's scheme, the Milankovitch astronomical cycles and the emergence of multiple glaciations

Following the Second World War a number of studies on the morainic amphitheatres was accomplished, based upon the Penck & Brückner scheme. Nangeroni (1954a) described the glacigenic deposits south of Lake Maggiore, Lake Lugano and south-west of Lake Como, formed by the network of interconnected Pleistocene glaciers descending from the Toce, Ticino and Adda drainage basins. Pracchi (1954) and Nangeroni (1954b) described the glacial deposits that can be seen along the two branches of Lake Como, while Riva (1957) mapped and described the morainic systems and outwash terraces south of Lake Como between the Olona and Adda rivers. Finally Vecchia (1954) described the Lake Iseo morainic amphitheatre. In a short summary of the five studies Nangeroni (1954c) concluded that Penck and Brückner's last three glaciations could be clearly distinguished on the basis of the morphology and surface weathering of three moraine systems and outwash terraces. Evidence of the Günz glaciation could only be found in deep sections, based on stratigraphiccriterial position. The maximum extent of glaciers decreased from Mindel, to the Riss and ultimately to the Würm glaciations. On the slopes of the Como and in the Iseo glacial troughs three different moraine systems could be distinguished from top downwards: 1- scattered erratics and residual moraine patches, locally deeply weathered; 2 - terminal morainic ridges; 3 - terminal 'morainic terraces'. Long profiles of major valley glaciers could be reconstructed for their maximum extent and elevation, and for the subsequent recessional stages.

An extensive and original revision of the Quaternary of the Po plain is contained in Gabert's (1962) PhD thesis: "*Les plaines occidentales du Pô et leurs piedmonts - Piémont, Lombardie occidentale et centrale*". This author studied the evolution of Po plain and its margins from the Miocene, from the Tanaro to the Adda river, and the Pleistocene piedmont-glacier morainic systems from the Dora Riparia valley to the Lecco lake. He recognised clear evidence of three major glacial advances which he equated to the Mindel, Riss and Würm glaciations. He recognized that the Würmian moraine systems are much better and extensively preserved than those of the Rissian. He also demonstrated that the main level of the plain (i.e. the Würmian outwash terrace) is linked to the last (Würmian) morainic arches and that the equivalent plain extends almost uninterrupted from the Stura di Demonte to the Adda river. Furthermore, the Pleistocene piedmont glaciers of the southern slope of the Alps advanced much less over the plain than those north of the Alps. Finally the moraines of successive glaciations are closer together in Italy rather than being more widely spaced as in Bavaria: the Würm moraines directly abutting those from the Riss.

From the late 1930s for more than three decades Sergio Venzo devoted himself to studying and mapping the Quaternary continental deposits of Northern Italy. In particular are to be mentioned here his studies of the lacustrine sections of Leffe (Venzo, 1950, Fig. 1c) and Pianico (Venzo, 1955) in the Bergamo pre-Alps, the geologic maps of the Lecco (Venzo, 1948) and of the Garda morainic amphitheatres (Venzo 1957, 1961, 1965) where he distinguished and mapped numerous groups of end moraines and related outwash terraces on the base of morphology and of the top soil sequences. He tried to correlate the succession of numerous palaeoclimatic changes - recognized in lithology and pollen diagrams of the long lacustrine sections and in the stratigraphic, morphologic and soil/palaeosol evidence of the Pleistocene glacigenic deposits at the foot of the Italian Alps - with the insolation astronomical cycles calculated by Milankovitch (1941).

In the pre-Mindel lacustrine sequence at Leffe, Venzo (1950) and Lona (1950, Fig. 1c) recognised five cold phases, that they correlated with three Donau and two Günz stadials, while in the Lecco and Garda amphitheatres Venzo (1948, 1965) distinguished on the base of morphology and weathering of moraines and outwash terraces the evidence of three glaciations, each subdivided into two-three cold phases (stadials). - The addition of three cold phases of the Donau glaciation (Eberl, 1930), as proposed by Milankovitch (1941), ten minima of the insolation curve could be correlated with the fourfold Penck & Brückner (1909) scheme. This was deemed possible provided each glaciation was split into two-three cold phases, assumed to represent stadials. In the absence of independent time control, these correlations were hypothetical, but the suggested large number of cold phases anticipated the quasi-periodic multiple glaciations of the Pleistocene that were subsequently recognised in the deep-sea deposits and the loess sequences.

3.4. Late-glacial and Holocene glacier fluctuations

By the end of the 19th century, attention was also payed to the geological evidence of Late Glacial and Holocene glacier fluctuations within the great Alpine valleys and near the front of the largest present-day glaciers. For example, Novarese (1915, 1916) described evidence for the post-Würmian stadials in the Aosta valley. These intervals were named Chambave, Aymaville and Courmayeur and correlated with the Bühl, Gschnitz and Daun stadials identified by Penck & Brückner (1909). Nangeroni (1930) described three stadial moraines in the Val Malenco (Sondrio), reconstructing the relative glacier extents and snow-line altitudes, and their tentative correlation to the Penck and Brückner's stadials. A few other studies on Late-Glacial moraines were published in the following decades, generally of only local relevance. Of particular significance are two studies by G.B. Castiglioni (1961, 1964) on the Late-Glacial moraines of the Mount Adamello-Presanella group and of the Dolomites. Following examination of the available study methods at the time (in the absence of numerical dating), the author concluded that three stadials could be identified in the two mountain areas. This was based on their average snow-line depression, compared to that at the beginning of the 20th century, which he correlated with the Sciliar, Gschnitz and Daun stadials, the locally an innermost moraine being attributed to the Egesen Stadial.

3.5. The Apennines

Beyond the Alps the presence of Quaternary glaciers on the Apennine mountains was first suggested from the Apuan Alps (Tuscany) by Cocchi (1867, 1872b), Stoppani (1872), and De Stefani (1874), on the Gran Sasso (Abruzzi) by Berruti & St. Robert (1871) and Di S. Robert (1884), on the northern Apennines by De Stefani (1887) and on the Southern Apennines by De Lorenzo (1892, Fig. 1b). These early reports were soon followed by more detailed descriptions by many other authors.

Northern Apennines and the Apuan Alps - Sacco (1893) presented the first reconstruction of the glacier occurence along the northern sector of the Apennines and on the Apuan Alps. Because of the lower altitude with respect to the Alps, they were mainly small glaciers on the north-facing side of the mountain chain, only a few valley glaciers reaching a length of few kilometres, as in Val Parma and in Val Cedra. Sacco (1893) mapped the occurrence and the extent of glacial deposits from north-west (Bobbio and S. Stefano d'Aveto) to south-east (Mount Cimone and Corno alle Scale), while De Stefani (1891a) mapped a dozen ancient glaciers with the glacial cirques, as well as the extent of the glaciers and of their moraines on the Apuan Alps.

Many other studies followed in the first half of the 20th century, among which were those by Losacco, who published a definitive memoir in 1949 and a revised edition in 1982. Losacco (1949, 1982) carefully described and mapped the geological and morphological evidence (glacial cirques, glacial deposits and terminal moraines) of 59 glaciers present in thirteen mountain groups, from the Ligurian to the Tuscan-Emilian Apennines. All the glacial deposits were attributed to the Würmian glaciation. For each palaeoglacier, the exposure, the maximum length, the maximum and minimum altitudes, and the snow-line altitude were reported. Only about ten valley glaciers reached a length of 5 km and only one was 8 km long (Parma valley), with a maximum thickness of 250 m. At least three recessional phases could be recognised in the majority of the mountain groups studied and recorded by nested terminal moraines in the highest parts of the valleys. By the third recessional phase the glaciers were almost all restricted to cirque tongues. Losacco (1949, 1982) gave the altitude of the glacial deposits, of the snow-line and the snow-line rise with respect to the glacier maximum for each of the three phases.

The reconstructed snow-line altitude (the average of the maximum elevation of enclosing mountains and lowest altitude of glacial deposits) during the maximum glacier extent raised from north-west to south-east from about 1300 m to 1600 m, while during the third recessional phase (correlated to the Bühl Stadial) was 250-320 m higher. The low altitude of the Late Pleistocene snow-line on the Northern Apennines was attributed to high annual precipitation (in the first half of the 20th century this exceeded 2000 mm/yr). A synthetic view of the distribution of Quaternary glaciers on the Northern Apennines and the Apuan Alps is published as a map by B. Castiglioni (1940).

Central Apennines - Following the first reports by Berruti & St. Robert (1871) and Di S. Robert (1884) on the past presence of glaciers on the Gran Sasso, many authors in the first half of the 20th century described the geomorphological and geological evidence of Pleistocene glaciers on the mountain groups of the central Apennines: Hassert , Sacco, Almagià , Crema, Klebersberg on the Abruzzi Apennines, Dainelli, Franchi, Biéler-Chatelan, Sestini, Beneo on the Simbruini- Ernici Mountains and Klebersberg on the Sibillini Mountains.

Suter (1939) carried out systematic studies of the Central Apennines for a decade. He concluded (Suter, 1940) that all the mountains higher than 2000 m were occupied by glaciers, as indicated by the presence of glacial cirques and moraines. He recorded over 200 cirques, mainly on the north and north-east-facing slopes. The floor of the cirques occurs at altitude of 1800-1900 m on the north-facing slopes, and 2200-2400 m on the south-facing slopes. A few U-shaped valleys are present, their floor reaching 150-300 m wide, with steep walls and trimlines marked by knickpoints. Well preserved terminal moraines can be found on the high plateaux including Campo Imperatore, Piano di Ovindoli, Piano Aremogna etc. In a few valleys two or three recessional moraines may occur. Suter (1940) considered that all the moraines were deposited during the last glaciation (Würmian) and that older, more weathered moraines could not be observed.

The size attained by glaciers on the Gran Sasso, Mount, Velino, Mount Greco and Mount Meta was 5 km or more (with a maximum of 10 km at Campo Imperatore), on the Sibillini, Simbruini, Terminillo and Majella mountains glaciers were 3.5 km long, while on the Matese, Mount Morrone, Sirente, Mount Cornacchia and Mount d'Ocre they were less than 3 km in length. These glaciers were 50-100 m thick, reaching a maximum of 200 m. The estimated snow-line altitude on the northern, eastern and western slopes was on average at 1750-1800 m, whilst on the southern slopes it stood at 2200-2300 m. Two to three recessional phases were found and tentatively correlated on the base of the rising of the snow-line to the Bühl and Gschnitz stadials. Within this latter stadial, glaciers disappeared from the Apennines, except on the Gran Sasso and Majella.

Based on the available knowledge, the distribution and the extent of glaciers from north to south, on the Umbria-Marche, Lazio and Abruzzo Apennines, were represented on the 1:1,200,000 map 'The Central Apennines during the Glacial Period' compiled by Sestini (1940).

After the Second World War, the evidence for pre-Würmian glacial deposits, hypothesised by Suter (1940), was reported by Demangeot (1963) from the Gran Sasso, and by Pfeffer (1967) from the Velino massif, both spreads being attributed to the Riss Glaciation.

Southern Apennines - Few studies were devoted to the glacial features on the Southern Apennines before the second half of the 20th century. De Lorenzo (1892) was the first to notice the evidence of an ancient glacier near Lagonegro (Basilicata). He described a terminal moraine in the Mount Sirino Group, represented by 'a great amount of mud chaotically including large and small blocks and pebbles of various size deriving from the surrounding calcareous and silicic rocks'. He saw many polished and striated pebbles in the moraine and rounded, polished and grooved rocks on the upstream flanks of the valley. With a sketch map and a section, he reconstructed the past valley glacier reaching about 3 km in length. Two further ancient glaciers were recognised from their terminal moraines by De Lorenzo (1893) in the same mountain group. The snowline altitude interpreted from the altitude of the glacial cirques was estimated at 1800 m. Indications of the past presence of glaciers on the Mount Pollino (2248 m) massif, at the boundary between Calabria and Basilicata, were described by Biasutti (1923) and Klebersberg (1932).

According to Suter (1939, 1940) the average altitude of the snowline at the Würmian maximum along the Italian peninsula was at 1500-1600 m on the Northern Apennines, at 1350 m on the Apuan Alps, at 1750-1800 m on the Central Apennines, rising to 1900-2000 m on the Southern Apennines. According to Trevisan (1940) the snowline rose from north to south with the increasing temperature along 5° of latitude, and from west to east as a consequence of decreasing precipitation from the Tyrrhenian to the Adriatic side. A map of the Würmian snowlines in the Mediterranean, compiled by Messerli (1967),shows their pattern along the Italian peninsula, substantially corresponding to Suter's conclusions.

4. CONTINENTAL QUATERNARY DEPOSITS: PALAEONTOLOGY AND CHRONOSTRATIGRAPHY

4.1. Palaeontological research from the late 18th century to the first half of the 20th century

The earliest accounts of invertebrate and vertebrate fossil records date back to the Renaissance period. Regarding the continental domain, the remains of Quaternary terrestrial mammals caught the attention of natural object collectors and scholars from various cultural backgrounds, and at much the same time the organic nature of fossils was first recognised (e.g., Boccaccio, Leonardo, Colonna, and Fracastoro) and that natural processes rather than the Great Flood were responsible for their accumulation (e.g., Moro, Volta, and Beccari).

Two of the most notable examples are Ferdinando I de' Medici's rich medicea Granducal collection of mammals from the Upper Valdarno (originally created in Florence and then moved to Pisa) (cfr. Cioppi & Dominici, 2010), and the report, at the end of the 16th century, of elephant bones (*Mammuthus meridionalis*) at San Giovanni Valdarno by the Pisan naturalist Andrea Cesalpino. Later, Francesco II de' Medici entrusted Giovanni Targioni Tozzetti, a collector of natural objects, with the task of reorganising the collection's remains kept at Pisa (Targioni Tozzetti, 1754). He not only played a crucial role in the analysis of the Upper Valdarno fossil mammal remains, highlighting their significance for comprehending the past flora and fauna life, but he also provided a thorough description of the deposits (some stratigraphical sections and lithologies) and their "natural products" (Targioni Tozzetti, 1752).

However, palaeontological studies, in which geological, palaeontological, and sometimes archaeological aspects were often intimately connected, multiplied by the end of the 18th and during the 19th centuries. The multidisciplinarity of interests was a common trait of many of the first scholars (e.g., naturalists, geologists, physicians, and natural object collectors) who dealt with mammalian fossil remains. Examples include, among others, Bartolomeo Gastaldi (1818-1879), interested in geology, glaciology, palaeontology, and palaethnology; Francesco Bassani (1853 -1916), geologist, palaeontologist, ichthyologist, seismologist, and volcanologist; and the engineer Romolo Meli (1852 -1921), whose scientific activity encompassed geology, palaeontology, malacology, and philology, as well as bibliographic studies.

Although there were several studies on Pleistocene marine invertebrates, particularly molluscs such as those from the Monte Mario Plio-Pleistocene sequence (Ponzi & Meli, 1887; Cerulli Irelli, 1905, 1907-1916), the study of mammals received a huge boost after the publication of the fundamental writings of the zoologist, biologist, and naturalist George Cuvier (1769-1832), considered the founder of vertebrate palaeontology (Cuvier, 1812, 1821-1824, 1836). The French scholar was in contact with Italian scientists, some of whom engaged him in the investigation of Pleistocene animal remains from the Italian peninsula and Sardinia. For instance, positive discussions and exchanges with Georges Cuvier encouraged Giovanni Fabbroni (1752-1822), a chemist and naturalist who investigated the collections of mammals from Upper Valdarno, to become more interested in palaeontology (Cioppi & Dominici, 2010).

During the 19th century, outstanding studies of the mammalian remains from the Valdarno Basini, as well as from other Tuscany basins (see e.g., Forsith Major, 1877, 1881, 1890; Ristori, 1897), led to the description and creation of new species still crucial for the systematics, biochronology, and evolutionary history studies of large Eurasian Pleistocene mammals. For instance, the naturalist and geologist Filippo Nesti (1780-1849) provided the first palaeontological description of proboscideans (mastodonts and elephants) from the Upper Valdarno Basin (Nesti, 1808). Moreover, he created the well -known species '*Elephas*' *meridionalis* (recte *Mammuthus meridionalis*) (the first elephant species to be reported in the Eurasian Early Pleistocene), based on the rich elephant Valdarno material he had discovered and described (Nesti, 1825). Later, Weithofer (1893) carefully described the proboscideans remains from Valdarno.

When, in 1860, Igino Cocchi (1827-1913, Fig. 1b) became curator of the palaeontological collections of the Physic and Natural History Museum in Florence, the study of Valdarno mammals had a further stimulus. The scientist not only studied some specimens (e.g., the *Macaca* remains, Cocchi, 1872a) and created the new well-known species *Equus stenonis* (Cocchi, 1867), but also enriched the collections with several acquisitions, including skulls of the large sabretoothed cats *Megantereon cultridens* and *Homotherium crenatidens*, the latter genus erected by Emilio Fabrini (1890) for material from Upper Valdarno (Cioppi & Dominici 2010).

Fabrini (1890) and then Domenico Del Campana (1915-1916) mentioned, under the name *Leopardus arvernensis*, the other large felid from the Early Pleistocene of Tuscany, *Panthera gombaszoegensis*. Del Campana also studied the Pleistocene canids from Tuscany, revising the species already defined by Fosyth Major (1877), *Canis etruscus* and *Canis falconeri* (= *Xenocyon falconeri*). The researcher created the species *Canis arnensis* for the remains of a smaller dog from Upper Vardarno that he had found and described, and he also created a new running hyaena species, *Lycaena lunensis* (recte *Chasmaporthetes lunensis*), for the material from Val di Magra (Del Campana, 1914). The palaeontologist also studied the fossil record, mainly the avifauna, from Apuane caves, including the rich mammalian material from the Equi cave and Tecchia (Del Campana, 1954).

Throughout the 19th and first half of the 20th centuries, several Italian and foreign scholars undertook geo-palaeontological surveys and investigations in central Italy, or they recorded and investigated recently discovered Quaternary mammal remains (e.g., among others, Battaglia, Bleicher, Ceselli, Clerici, Indes, Lartet, Napoli, Neviani, Rellini, Terrigi, and Verneuil). Here, we would like to recognise the researchers that offered fascinating information on the Pleistocene deposits and their mammal fossil record of the Roman Basin, including the Rome metropolitan region, where vertebrate fossil remains were reported since the 16th century (e.g. Mazzaella, de Mancony, Lancisi and Calmet) and Morozzo cited the discovery of an elephant fossil in the early 19th century (Kotsakis & Barisone, 2008). The biologist Giuseppe Ponzi (1805-1855), thought to have graduated in medicine, devoted himself to geological and palaeontological investigations. A consequence of his notable studies of the Roman and Tyrrhenian coast area cartography and geology, he has been considered the founder of the Roman geological research school. As regards palaeontology, he revised the mammalian remains of some collections, studied new material, and discussed taxonomic and systematic issues in some cases. He compiled the first inventory of the Roman mammalian associations, attempting to gather them into four chronologically homogeneous groups. He then proposed an assessment of their chronostratigraphic order, tentatively placing them from the Miocene-Pliocene to the modern epoch (cf., among several others, Ponzi, 1862a, 1862b, 1875, 1878, 1883).

Giuseppe Augusto Tuccimei (1851-1915), a physician, canon lawyer and naturalist, was a pioneer in geological and palaeontological research. In his studies of large and small Plio-Pleistocene mammals, he mostly described Villafranchian species, not only reporting the remains found during field surveys and excavations, but also providing a systematic review of some taxonomic groups (Tuccimei, 1889).

Romolo Meli (see above) studied the geology, the stratigraphical assessment, and the palaeontological content of various Plio-Pleistocene Latium deposits. His research activity was particularly devoted to the Upper Aniene Valley, the Roman Campagna, and the Rome metropolitan area, where he first recognized the significance of the Pleistocene settlement of Sedia del Diavolo (Meli, 1882).

The naturalist Alessandro Portis (1853-1931), who had carried out significant geological surveys in northern and central Italy since 1891, largely devoted himself to the study of the Quaternary deposits of the Campagna Romana and their mammalian content (Portis, 1893-1896), mostly describing the remains of elephants, carnivores, hippopotamuses, and large and medium-sized artiodactyls, also dealing with systematic issues (Portis, 1920). He expanded time by time his research activity to other Latium areas, such as the Oricola-Carsoli basin, where he found several bones of an elephant skeleton, showing in his opinion some similarities with both *M. meridionalis* and *'Elephas' antiquus* (recte *Palaeoloxodon antiquus*) (Portis, 1893-1896, volumes 1 and 2), to which the elephant was then referred by De Angelis d'Ossat (1956).

Enrico Clerici, the engineer (1862-1938), geologist and naturalist, conducted several surveys and applied innovative methodological laboratory approaches to support his geological, palaeontological and mineralogical researches. Together with relevant studies on Quaternary invertebrates (mainly malacofauna, plants and diatoms), he studied mammal remains from most of the taxonomical groups, not only from a systematics point of view, but also considering their palaeoenvironmental context (e.g., Clerici, 1888, 1932, and references therein).

The versatility of the geologist Gioacchino De Angelis d'Ossat (1865-1957) is demonstrated by the breadth of his study interests, which included palaeontology, philosophy and geology. His research activity was mainly focused on Latium and the Roman basin (for example, his study of the Aniene Upper Valley). Among his palaeontological studies, those related to the Quaternary are mainly concerned with mammals. After his juvenile work on the woolly rhinoceros (De Angelis d'Ossat, 1895), he mostly studied proboscideans, especially *P. antiquus*. The study of elephants and the Velia hill's deposits (via dei Fori imperiali, Rome) (De Angelis d'Ossat, 1897) is among the most well-known. It provides an extraordinary and detailed geo-palaeontological documentation of an area that is now completely urbanised.

In the 19th century and until the 1960s, several geologists and palaeontologists (e.g., Airaghi, Anelli, Cornalia, Forsyth Major, Gastaldi, Mariani, De Stefano, De Angelis D'Ossat, Portis, Sacchi Vialli, Stoppani, Zuffardi) dealt with North Italian Quaternary mammal remains. Some of these fossil remains were retrieved from alluvial deposits of the main rivers; others were found in caves and occasionally in glacial deposits. The initial research activities carried out in the lignite deposits of the Leffe basin are among the most relevant. Since the first report by Balsamo Crivelli (1840, 1842), studies of the Leffe large mammals (particularly elephants and rhinoceroses) by various researchers (e.g., Airaghi, 1914; Caffi, 1934; Vialli, 1956) have highlighted their significance for the biochronology of the Early Pleistocene mammalian fauna from Italy.

Regarding Southern Italy, a first inventory of mammalian remains was provided by Flores (1895). Various researchers reported mammal remains found in cave archaeological deposits (e.g., Blanc G.A.,1920, 1928; Botti, 1874,1890; Graziosi & Maviglia, 1946; Mochi, 1911, Rellini, 1920), while palaeontological and archaeological research of significance was carried out by De Lorenzo and D'Erasmo (e.g., De Lorenzo & D'Erasmo, 1927, 1932).

Giuseppe De Lorenzo (1871-1951), geologist, palaethnologist and palaeontologist but also a botanist, philosopher and poet, boosted the development of geological studies in southern Italy, especially in Basilicata. However, he carried out research throughout Italy, mainly dealing with volcanology but also with glaciology. His palaeontological studies mostly concerned the study of southern Italy's straight-tusked elephants and their contemporaneity with the Palaeolithic man.

The pre-eminent research activity of the naturalist Geremia D'Erasmo (1887-1962) was related to fossil fishes, for which he became a well-known specialist. He also conducted extensive research on southern Italian mammals, including hippopotamouses, and carefully studied fossil proboscideans, some of which he discovered in the Sele and Liri basins. He discussed the contemporary presence of Palaeolithic man in those territories, as the numerous artifacts found both in the fossiliferous deposits and elsewhere document. In the first summary on elephants he published in collaboration with De Lorenzo (De Lorenzo & D'Erasmo, 1927), D'Erasmo discussed the belonging to *P. antiquus* of various remains of proboscideans and attributed some remains from Abruzzi and Lucania to *M. meridionalis*. In the 1950s, he discovered and described the skull of a young straight-tusked elephant from the well-known Pignataro Interamna site (Montcharmont Zei & D'Erasmo, 1955).

4.2. The earliest studies of the endemic fauna of the two major islands, Sicily and Sardinia

Francesco Anca and Gaetano Giorgio Gemellaro were two of the most influential Sicilian researchers. Anca, an agronomist and zoologist, regarded as the father of Sicilian Palaeontology, was particularly active in the study of the Quaternary mammals from Sicily, notably those present in ossiferous breccias and cave deposits (e.g., Anca, 1860). Gemellaro, a physician and naturalist best known for his research on Mesozoic invertebrates and squalodonts, also studied mammals found in Pleistocene cave deposits (Gemellaro, 1866). The collaboration of the two scholars led to the first attribution of fossil Sicilian elephants to dwarf endemic species (Anca & Gemellaro, 1867).The dwarf elephants are the most significant and intriguing of the Sicilian large mammal endemic species a result of the morphological and dimensional variety of their outstanding fossil record.

Cupani (1713) in the early 18th century was the first to mention, fossil elephant remains, i.e., a tooth (Fig. 1a), but he did not recognise their actual nature. During the 19th century, various scholars described Sicilian dwarf elephants, enhancing knowledge of their diversity (e.g., in chronological succession, Scinà, Anca, Gemellaro, Minà Palumbo, Dalla Rosa, Doderlein, Stöhr, Pohlig, De Gregorio, etc.) (Palombo et al., 2021 and references therein). These studies represented a substantial source for the seminal Vaufrey's study of the Mediterranean dwarf elephant taxonomy and evolution (Vaufrey, 1929).

The Sardinian Pleistocene vertebrate fauna has caught researchers' interest since the discovery of endemic mammalian remains in the early 19th century. The first surveys of Quaternary deposits on the island and studies of their fossil content were carried out by the German anatomist and physiologist Rudolf Wagner (1805-1864, Fig. 1a). He created the first Sardinian endemic species, i.e. *Prolagus sardus*, for the remains of a large lagomorph that are extremely abundant in the Late Pleistocene and Holocene Sardinia deposits (Wagner, 1829). In the same period, General Alberto La Marmora, during his exploratory trip throughout Sardinia, collected vertebrate fossils from various sites, including the ossiferous breccias of Monreale-Bonaria (Cagliari). The mammalian remains found at the site were entrusted for study to the Pisan physician Cesare Studiati (1821-1894), who in 1857 erected the new genus and the new species *Cynotherium sardous* for some dental remains and an incomplete mandible of a small canid (Studiati, 1857), with uncertain and debated phyletic relationships (cfr. Zedda et al., 2022 and references therein).

Forsyth Major was the primary researcher on the Quaternary Sardinian vertebrate fauna in the late 19th and early 20th centuries. He conducted new surveys and studied mammalian remains either recently discovered or from old collections. The Scottish scientist created the species '*Elephas lamarmorae*' (recte *Mammuthus lamarmorai*), based on an almost complete skeleton from the Funtana Morimenta area (Gonnesa) (the first discovered Sardinian elephant) that Acconci had already described in 1881 (Forsyth Major, 1883). In 1882, he also created the species '*Arvicola' henseli* (recte *Microtus henseli*) for a large arvicolid found in an unknown Corsican locality and *Enhydrictis galictoides,* based on a large endemic Galictini remains found in the Pleistocene deposits of Monte S. Giovanni (Forsyth Major, 1901).

Reinhold Friedrich Hensel, a German naturalist, described the remains of a shrew from the Monreale Bonaria breccias as *Sorex similis* (= *Asoriculus similis*) In the 1850s, as well as a new murid species, *Mus orthodon* (= *Rhagamys orthodon*), whose provenance from the same deposits is unknown.

The French geologist and palaeontologist Charles Jean Julien Depéret carried out some research in the Corso-Sardinia Massif and created in 1897 the well-known species "*Cervus (Eucladoceros)" cazioti* (recte *Praemegaceros cazioti*), a common component of the Late Plestocene Sardinian fauna assemblages, based on a few antler and mandible fragments from the Nonza cave (Corsica) (Depéret, 1897).

At the beginning of the 20th century, Emile George Dehaut conducted some surveys and investigated the Capo Figari (Olbia) breccia, finding several vertebrate remains. The French palaeontologist erected the species '*Antilope melonii*' (recte *Nesogoral meloni*) for the skull of a small bovid partially embedded in a hard breccia matrix (Dehaut, 1911). The peculiar characteristics of most of the Capo Figari remains hamper the possibility of firmly recognising the morphological traits of their continental ancestor. This is the case, for instance, of a large fragment of a small skull that Dehaut ascribed to a primate, '*Ophthalmomegas lamarmorae*', while it belongs to a small endemic owl, *Bubo insularis*. In the Early Pleistocene the Capo Figari promontory was actually inhabited by an endemic dwarf macaca, as documented by the find of a lower molar (Dehaut, 1914) and especially by the material collected by Forsith Major during his systematic excavations. The Italian palaeontologist Augusto Azzaroli (Fig. 1d) studied a well preserved skull and created for the Capo Figari cercopithecide the new species *Macaca majori* (Azzaroli, 1946).

Since the second half of the 20th century, new studies and discoveries have notably enhanced our knowledge of the Pleistocene insular mammalian fauna from Sardinia and Sicily (e.g., Palombo 2018).

4.3. Note on the first attempt at a chronological assessment of Quaternary continental sediments

The study of continental Plio-Pleistocene strata and the fossils they contain has a long history in Italy. In the Renaissance, one of the earliest researchers to conclusively determine the organic nature of fossils was Leonardo da Vinci, far before Ulisse Aldrovandi invented the term 'Geology' in 1603. In the Leicester Codex (1506-1510), he mentioned, for example, the 'njchi' (shells) of the Arno deposits, whose alluvial origin he acknowledged, as well as of the Piacenzian deposits of the Parma and Piacenza hills. He claimed that in the past, the sea had occupied the Po Valley (De Lorenzo, 1920; Ligabue, 1977). Three centuries later, Abbot Antonio Stoppani, geologist and palaeontologist, reiterated Leonardo's assertion, but to contest the glacial theory. Indeed, he affirmed that, in the Quaternary, the Adriatic occupied the entire Po valley, penetrating into those valleys that would be occupied later by glaciers and then by lakes.

However, the first continental stage was defined only in the second half of the nineteenth century when Pareto (1865, Fig. 1b) proposed the "Piano Villafranchiano", indicating Villafranca d'Asti as the type area, for a sequence of terrestrial sediments to fluvial and lacustrine present in the sedimentary basin of Villafranca d'Asti (Piedemont). Subsequently, Gignoux (1916) proposed a correlation of this stage with his marine Calabrian, at that time considered late Pliocene in age (see above). The Villafranchian definition is based on the palaeontological content, mainly mammals, of these strata. In this acceptance, for instance, the name was first used in the description of the central Italy fossiliferous deposits by Tuccimei (1889). The comparison of this mammalian fauna with other Late Pliocene-Early Pleistocene mammalian faunal assemblages from Italy, i.e., those of the Valdarno Basin, which began in the 1970s, led to the definition of the Villafranchian European Land Mammal Age "ELMA" (Azzaroli, 1970, 1972, 1977), still widely used as a Eurasian biochronological unit. Accordingly, the term 'Villafranchiano' lost its original chronostratigraphical significance, although the name 'Villafranchian succession' is still maintained for historical reasons only for the deposits of the Villafranca d'Asti basin. Through the course of time, the stratigraphy of the Villafranchian basin has been substantially revised (see e.g., Carraro ed., 1996), even through multidisciplinary research (e.g., Forno et al., 2015).

In the first half of the 20th century, geologist Alberto Carlo Blanc (1906-1960, Fig. 1c), who had a keen interest in archaeology and palaeoanthropology, conducted important research on the Quaternary deposits of Lazio (e.g., Agro Pontino, Circeo, and the Tiber and Aniene valleys). Following the discovery of the second skull of Saccopastore (Rome, Fig. 1c) he made with Abbot Breuil, (see below) (Breuil & Blanc, 1935a, 1935b), Blanc and collaborators intensified the geological investigations of non-marine Pleistocene sections in the Roman area, then expanded to the Torreinpietra site and surrounding area. These investigations led to the detection of major erosional phases, assuming that the sedimentary sequences would be deposited during glacial cycles. As a result, the researchers defined 'five glacial periods' (Acquatraversan, Cassian, Flaminia, Nomentanan and Pontinian) that they correlated with five Alpine glacial phases, from Donau to Würm (Blanc, 1955, 1957, 1958; Blanc et al.,1954,1955a,b). Although the erosional phases actually correspond to sea-level lowering and low stand during glacial stadials, while the sedimentary successions have been mainly deposited during interglacial cycles, Blanc's studies and its attempts to chronologically order the main stratigraphical Roman basin events, offerred the basis for the future development of the continental deposit chronostratigraphy in the area.

5. FOSSIL PLANTS, THE DAWN OF THE QUATERNARY AND GLACIATION

At the dawn of stratigraphy in the last decades of the 18th century, the Linnean system of plant taxonomy was universally accepted by plant systematics (the 10th edition of Systema Naturae was published in 1758) and the botanical nomenclature (Species Plantarum, 1753) was used by the several botanists exploring the Old World (Linnaeus, 1753,1758). In the third decade of the 19th century, systematic palaeobotanists shared the concerns for a natural classification of fossil plants (Brongniart, 1828), based not only on external and reproductive but also on anatomical characters (Cuvier, 1821-1824). Comparison of dispersed fossil plant parts with the whole-organism morphology of related modern living genera and species laid the foundation for comprehensive fossil floras and shed light on the relationships between fossil forms and the respective living taxa (Sternberg, 1820-1828; Brongniart, 1828-1838). Plant diversity of Tertiary strata mostly belonged to extinct species (Unger, 1850), an evidence suggesting the need for a most recent geological period: "we claim for a subsequent period, i.e. the Quaternary, which is characterized by animal and plant species similar to modern living ones at the same site" (Reboul, 1833). However, at that time, comparing a fossil plant part with similar, yet described ones, was critical, due to shortages in material collection of either fossil or living taxa, and to poor assessments of world phytogeography. An example derives from *Juglans bergomensis* described by Balsamo Crivelli (1840) (the tale was reviewed by Martinetto et al., 2015). Several decades later, Sordelli (1873, 1878, 1896, Fig. 1b) was able to specify the aliquot of Tertiary species, presently extinct or eradicated from the Alpine flora, which were still occurring at several macrofossil plant deposits from Lombardy, clearly distinguishing the Quaternary records from the marine Pliocene leaf sites, and recognising three steps in the biochronological framework of plants in the Alpine Quaternary. An early step, considered to pre-date the diluvial and glacial events, was assigned to the Villafranchian, intended as a biochronological unit pinpointing the transition at the end of the Pliocene (Pareto, 1865). The following intermediate step, rich in elements from the Pontic Flora, was found at the classical sites of Piànico-Sèllere, Re in

Val Vigezzo and the Hötting breccia of Innsbrück (Baltzer, 1893; Wettstein, 1892). The absence of far-Asiatic and Pontic elements in the most recent 'post-glacial flora' recorded from peat and calcareous tufa post-dating the glacial moraines of northern Italy (Villa, 1864, Neuweiler, 1905; Andersson, 1910) was related to a range contraction of temperate plants following the Quaternary glaciation cold-climatic interval (Sordelli, 1896). Likewise, the many Asiatic elements, typically recovered from the Leffe record in the Italian Alps, disappeared sharply after the Villafranchian, implying an early glacial event, corresponding to the multi-glacial theory promoted at the end of the 19th century (Penck et al., 1894). Ultimately, moving from the idea that observed changes between plant assemblages were not gradual through the course of the Quaternary, but instead they were framed by multiple cold intervals, the concept of interglacial floral assemblages emerged (Baltzer, 1893; Sordelli, 1896). Meanwhile, macrofossil plant sites raised another issue, which was to remain unsolved for many decades, i.e. the finds of temperate forest floras apparently present within glacial sequences (Baltzer & Fischer, 1890; Sordelli, 1896).

5.1. The origin of terrestrial pollen stratigraphy in the Quaternary of Italy

Stratigraphical palynology originated as a tool to establish a time correlation between post-glacial peat sequences in Sweden (Von Post, 1909, 1916; see Manten, 1967 for a review). In the first decade of the 20th century, the palaeofloristic school of northern Europe was addressed to recognise the succession of macrofossil assemblages recovered from post-glacial peat (Andersson, 1898). Neuweiler (1905) and Andersson (1910) visited peat basins in northern Italy, which were being excavated for fuel, and recognised an early post-glacial phase that included pine macrofossils, followed by oaks and warm-temperate aquatics, which were related to climate changes and to prehistoric dwellings. The concept that climate changes and human impacts could be interpreted from the stratigraphical study of apparently monotonous and short-lived peat sequences was perceived by the Italian geologist Taramelli (1910). This may be considered the foundation of the interdisciplinary high-resolution Quaternary stratigraphy we know today. Vegetation has the advantage that it integrates the climate over a number of years, and trees have a lifetime of decades (Hay, 2013), comparable to a single human generation. Despite these promising premises, the first pollen analyses in Italy were delayed until 1929, when Giuseppe Dalla Fior (Fig. 1c) and Paul Keller independently addressed the study of peat sites at the southern foothills of the Alps (Keller, 1931, Fig. 1c) and in the Venezia Tridentina (Dalla Fior, 1931, 1932, 1935). They disentangled the post-glacial forest history and found microbotanical evidence of prehistoric human impact on natural vegetation, i.e. at the pile dwelling of Molina di Ledro (Dalla Fior, 1940). The long debated Pleistocene issues related to the succession of glaciations and their ecological impact were soon tackled by palynologists. The first pollen record of an alleged interglacial flora at Civezzano (Dalla Fior, 1933) revealed the image of a temperate forest. Later, the naturalist Pietro Zangheri carried out the first analysis of the glacial period in the subsurface of Forlì, on the Apennine side of the Po Plain, looking for the glacial and post-glacial history of pines in relation to the origin of the Pineta di Ravenna (Firbas & Zangheri, 1935). Dalla Fior may henceforth be considered the founder of stratigraphical palynology in Italy, his interests in palynology being stimulated by the phytogeographer Giuseppe Gola (Ferrari, 1977).

5.2. After the Second World War. Pollen records of Pleistocene plant diversity and climate change from lacustrine-palustrine records

The potential of stratigraphical palynology to afford difficult problems in palaeoclimatology and Pleistocene palaeoecology emerged soon after the identification of insolation astronomical cycles (Milankovitch, 1941). As presented above (section 3.3), Italian Quaternary geologists encountered substantial difficulties correlating the classical Penck & Brückner (1909) four-fold scheme of glaciations with the minima of the insolation curve, given the complexity of mathematical climate solutions and the discontinuity of the glacial record. Fausto Lona (Fig. 1c), a palaeobotanist, formed with Dalla Fior (Lona, 1941) within the strong botanical group active in the thirty years at Trento (Tomasi, 2010), was recruited to the Botanical Institute in Milano by the botanist Sergio Tonzig and, after the Second World War, invited to investigate the pre-Mindelian lake record at Leffe by the geologist Sergio Venzo (Fig. 1c). In the 1940s, the narrative about the vegetation history of early Quaternary intervals was vague and its microbotanical diversity was unsuspected. However, the long lake record preserved in the Leffe Basin in the Italian Alps (Fig. 1c) held a number of opportunities: (i) it had virtually continuous sedimentation, it represented over 70 metres of lacustrine sediments and brown coals ('lignites') (Venzo, 1950); (ii) it had good pollen preservation and (iii) it was situated close to the early glacial moraine systems (Venzo, 1950), the oscillatiory behaviour of the glaciers indicated by which at the end of the Villafranchian Mammal Unit (Gignoux, 1943) was to be proved in the Alps. Hopefully, the pollen record by Lona (1950) and Lona & Follieri (1957) illustrated a continuous sequence of ten phases of contraction of coniferous forests and timberline depression related to cold events, alternating with phases of mixed broad-leaved warm temperate forests, forming pollen assemblage cycles of varying amplitude. Thus, the Leffe sequence demonstrated, for the first time, the fine structure of the terrestrial climate history that characterises the European Early Pleistocene. These complex oscillations were believed to correlate with the early glacial phases of Donau and Günz and to span the entirety of the Late Villafranchian up to the early phases of the subsequent Cromerian Stage of Western Europe. This terrestrial correlation was presented in detail in a first terrestrial Pleistocene teleconnection (Zagwijn, 1957). A few years later, after completion of the microbotanical record (Lona, 1962, 1963; Lona &

Bertoldi, 1973), it was concluded that all the warm intervals were to be considered interglacial in character, thus tuning the record to the global climate cyclicity observed in the first available Early Pleistocene marine sediment isotope records (Shackleton & Opdyke, 1973, 1976, 1977).

The research topic on Pleistocene lacustrine-palustrine pollen stratigraphy was then expanded to explore the ecological history preserved in several intermontane basins and Plio-Pleistocene marine sequences in peninsular Italy (Lona & Ricciardi, 1961; Lona et al., 1969; Lona & Bertoldi, 1972, 1973).

At the conclusion of the present contribution, it is worth mentioning the legacy of Fausto Lona in the formation of contemporary research groups of Quaternary terrestrial palaeoecologists in Italy. His scholars Maria Follieri (1956,1958a,b and foll.) and Daria Bertolani Marchetti (1954, 1955, 1957 and foll.) established laboratories in which long-standing and productive activity in all branches of Quaternary palaeobotany and archaeobotany flourished. Moreover, in the 1950s, Arturo Paganelli (1956, 1958, 1959 and foll.) formed an important research centre at Camerino, under the direction of Vittorio Marchesoni.

5.3. The early stages of archaeobotany and interaction with Quaternary studies in Italy

The early history of studies on plant remains contained in deposits formed by human agency can be paralleled to the evidence offered by early archaeological excavations in the Vesuvian area. Already in 1740 carbonised plant remains found in Herculaneum were recognised and exhibited (Mariotti Lippi et al., 2014). The first archaeobotanical report from Pompei is dated to the third decade of the 19th century (Covelli, 1827).

By the first half of 19th century, the first comprehensive fossil floras were being published (see section 5). Several plant records were analysed from settlements of Roman age (De Luca, 1863, 1879), but especially from waterlogged and hydromorphic deposits nearby to prehistoric wetland settlements, preserving very rich assemblages both in anthropic and in semi-natural plants. These studies enjoyed success after the discovery of lake-dwellings in the circumalpine region (Keller, 1854), since Heer (1865) demonstrated the importance of the investigations on these waterlogged plant remains (Jacomet, 1998). A large array of pile dwellings and Terramaras, being excavated for fuel or for manure in northern and central Italy, yielded rich archaobotanical assemblages, readily identified and connected to human consumption and construction (Strobel and Pigorini, 1864; Lioy, 1876; Sordelli, 1880; Scarabelli, 1887). Although, several of these peat archives were soon destroyed and the fossil materials dispersed, even those sites still represent a reference for cultural biochronology today. The famous Torbiera of Lagoni di Mercurago, first studied by Gastaldi (1862) in connection with fuel exploitation, was depleted. Likewise, after recent drillings (CNR-IDPA, 2013), the deposit of the Torbiera of Polada, whose name is taken as a cultural reference for the early Bronze Age in the Garda Lake region (De Marinis, 2000), turned out to have been exhausted by quarrying. By the beginning of the 20th century, archaeobotanical synthesis became available for Italy (Neuweiler, 1905). The archeobotanical biodiversity was also compared with diluvial, or “Quaternary” floras, i.e. unaffected by human action (Sordelli, 1878, 1896). At the end of 19th century, the archaeobotanical discipline was still seen as the study of human agency on plants in a ‘post-Quaternary’ context. For a review on further developments of palaeobotanical disciplines in Italy in the last sixty years, consult Paganelli and Bertolani Marchetti (1988) and Mariotti Lippi et al. (2014).

6. A BRIEF ACCOUNT OF THE EARLIEST PALAETHNOLOGICAL STUDIES AND THE FIRST REPORTS OF PREHISTORIC HUMAN REMAINS IN ITALY

6.1. A look back at the beginnings of palaeoanthropological research in Italy

The ancient beginnings of the human species have been upheld since the Classical Epoch by philosophers, historians and poets, including Plato, Herodotus, Diodorus Siculus, Strabo and Lucretius, who also claimed that there was a time when humans did not know metals but instead worked rough stones. Later, in the 16th century, the physician and naturalist Michele Mercati (1541-1593) reaffirmed this concept, claiming that ancient humans used lithic arms. In the Classical Epoch, illustrious people collected Palaeolithic tools and fossil bones. For example, Svetonius tells us that in the Emperor Augustus's villas there were bones of "gigantic beasts", prehistoric arms and stone hatchets collected by him on Capri Island.

In the 18th century, some naturalists, theologians, archaeologists and historians, such as Antonio Vallisneri (1661-1730), Giovanni Antonio Bianchi (1686-1768), and Luigi Antonio Lanzi (1732-18109), mentioned prehistoric ’arrows‘.

However, the scientific debate on the anthropogenic origin and age of lithic implements did not start until the early 19th century, promoted by the report by Boucher de Perthes, a geologist and antiquarian, of some lithic implements he had discovered and collected in the Palo cave (Rome) in 1810 and then in France in the Somme basin. This event also encouraged the beginning of research activities and excavation campaigns. Even in Italy, the presence of prehistoric man (human remains and artifacts) was definitively confirmed in the 19th century by the activities of some scholars, such as Luigi Ricci (1823 - 1896) and his son Corrado Ricci (1858-1934), founder of the Institute of Archaeology and History of Art, Arsenio (1828-1900) and Domenico Crespellani, founders of Modena archaeology, and Stefano De Stefani (1822-1892), who devoted himself mainly to survey and excavation campaigns such as those in the Monte Lessini territory. In the 19th century, however, the discovery and study of Palaeolithic artifacts were mainly the research activity of geologists such as Falconer, Anca and Gemellaro (see above), while palaethnologists focused on Neolithic, often attributing to it even hand-axes and Mousterian implements (except for those found in an indisputable stratigraphical context).

The true nature and antiquity of Palaeolithic artifacts were widely acknowledged in the early 20th century. Gian Alberto Blanc (1879-1966), a physicist, geochemist and palaeontologist, and his son Alberto Carlo Blanc (see above), provided a fundamental contribution to the development of Italian Palethnology through their fieldwork and studies.

Pioneering studies of the Palaeolithic are attributed, for instance, to Ippolito Cafici (1857-1947), who was in contact with Chierici, Pigorini and Strobel actively contributing to scientific debates; Raffaello Battaglia (1896-1958), who mainly carried out research in the fossiliferous caves of Venezia Giulia and discovered the Valcamonica's graffiti and engravings; Carlo Maviglia (1897-1956), who carried out research throughout Italy, from high altitude alpine sites, to Lombardy, to Basilicata (i.e., Vulture Basin), and to Sicily(e.g., San Teodoro cave, Messina); Luigi Cardini (1898-1971), who carried out, for instance, notable research at Balzi Rossi and in the Latium area; Franco Anelli (1899- 1977), a palaeontologist and speleologist, who studied cave deposits in northern Italy; Paolo Graziosi (1907-1988), the founder of the "*Rivista Italiana di Preistoria e Protostoria*", who focused attention especially to Mousterian cave and Upper Palaeolithic deposits. This is to mention just a few among several other scientists.

Since the second half of the 20th century, research activities have become sensibly enhanced and the results of the studies of the palaeothnological record proven, taking advantage of new investigation methods and the support of other disciplines.

6.2. The most noteworthy Palaeolithic human remains discovered from the 18th and the first half of the 20th century

The palaeoanthropology - of which Édouard Lartet (1801-1871), palaeontologist, geologist, and anthropologist is considered the founder - substantially established itself as an autonomous science in 1856, when the remains (a skullcap and elements of the postcranial skeleton) of Homo neanderthalensis were discovered in 1856 in the Kleine Feldhofer cave (Neander valley, Feldhof, Germany).

The first reports of Pleistocene human remains discovered in Italy (*Homo sapiens*) date from the1790s, when Emile Rivière reported two child burials (1874) in one of the caves (Grotta dei Fanciulli, Fig. 1b) of the Balzi Rossi site (Liguria). Other burials were discovered at the same site in 1884 by Louis Jullien at Balma Grande Cave (an adult male skeleton covered by ocra), then in the same cave by Giuseppe Abbo in 1892 (three burials of an adult male and of young and adolescent females), and then in 1894 (two adult males). Finally, in 1901, Léonce de Villeneuve discovered a single burial with the skeletons of an old and an adolescent female in the Grotta dei Fanciulli cave.

The Arene Candide Cave is another renowned site located on the north-western Liguria coast with burials of anatomically modern humans. The Arene Candide Cave necropolis has yielded numerous burials dating back to the terminal phases of the Pleistocene (Epigravettian). The cave was first discovered by Issel in 1864, but the first excavation campaigns took place in the first half of the 20th century, carried out in the south-eastern sector of the cave by Luigi Cardini in 1940-42 and then, in 1948 -50, with Luigi Bernabò Brea. The research revealed a long stratigraphical sequence, spanning from the Upper Palaeolithic to the Byzantine epoch, and led to the discovery of several Upper Palaeolithic burials. Among the nineteen burials, the most famous is that called 'Giovane Principe' because of the very rich equipment found in the burial. The skeleton, discovered in 1942, covered with red ochre, belongs to a fifteen year-old hunter, 1.70 m tall, with very strong arms, especially the right one that threw spears while hunting (Cardini, 1942, 1980).

The first remains of *H. neanderthalensis* had already been reported in 1929, when Duke Mario Grazioli discovered the almost complete skull of a mature female in the gravel quarry at Sacco Pastore, on the left bank of the Aniene river in a rural area, today within the city of Rome. The discovery was communicated by Sergio Sergi who also studied the skull (Sergi, 1929, 1944). A few years after the discovery of this skull (Saccopastore I), the quarry was abandoned. During a geo-palaeontological survey in the Saccopastore cave in July 1935, Alberto Carlo Blanc and Abbot Henri Breuil found, the incomplete skull of an adult male (Saccopastore 2, Fig. 1c), lacking the entire vault, part of the base, and the left fronto-orbital areas (Blanc, 1942, Sergi, 1948).

Four years later, on February 25, 1939, Alberto Carlo Blanc discovered a well-preserved third Neanderthal skull (Fig. 1c), belonging to a male approximately 40 -50 years old in the Grotta Guattari cave (Circeo Mountain) (Blanc, 1942). The discovery had great resonance also for the peculiar positioning of the skull, found in the centre of the cave, surrounded by a ring of stones and for the presence at the base of the skull of a hole at the time interpreted as the result of an anthropogenic action aimed at removal of the brain, namely ritual cannibalism. This hypothesis was long and hotly debated until it was definitively clarified that the hole was created by a hyaena gnawing (White et al., 1991).

From the second half of the 20th century onwards, new discoveries notably increased the Italian fossil record of Palaeolithic human remains, especially those not belonging to Anatomical Modern Humans (AMH). These are currently recorded from 37 sites, ranging in age from the early Middle Pleistocene (e.g., the femur diaphysis from Notarchirico, Vulture basin, dating to MIS 16: i.e. Cromerian Complex Stage) to MIS 3 (i.e. Mid-Würmian) (e.g., the mandibular fragment from Archi, Calabria and the Grotta Breuil, Circeo Mountain, skull fragment). The variety of the fossil record suggests a new scenario for the evolutionary dynamics of the Palaeolithic human population in Italy. A state-of-the-art on pre-modern human fossils of Italy is presented in Buzi et al. (2021).

7. CONCLUDING REMARKS AND PERSPECTIVES

In this short review, the authors have attempted to outline the main research lines pursued on the Quaternary in Italy, from the 18th to the mid-20th century, by scholars of natural history, geology, palaeontology and prehistoric archaeology. In general, they devoted themselves to many different research topics from the most various periods of the Earth, with the partial exception of those who studied the traces of prehistoric man. The results of all these studies formed the foundations of a progressive specialisation along more clearly defined research lines in the years that followed, as well as a renewed interest in the past climate and environmental changes in comparison to climate change and the exponential increase of human impact.

Following the long tradition of biostratigraphical research on the marine Neogene and Pleistocene sequences in Italy, the study of marine Quaternary deposits made important contributions to the definition of the Pliocene-Pleistocene boundary and of the Pleistocene stages/ages.

The Quaternary marine sections have been defined with increasing chronostratigraphical precision and detail as a result of multidisciplinary study and the gathering of new data. The stages previously proposed have been reconsidered, some redefined, and their rank reevaluated (Capraro et al., 2022; Capraro & Maiorano, 2023).

The Gelasian and the Calabrian (the first and the second stage of the Pleistocene Series, Quaternary System) have both been formally ratified. After the first fundamental work of Azzaroli (1977), which set the basis of the mammalofauna biochronology, various schemes have been proposed in attempt to order chronostratigraphically the continental terrestrial deposits according to their fossil mammal record. In the course of time, new discoveries and new data alter the schemes hitherto suggested, requiring revisions and new proposals (cf. e.g., Palombo, 2021 and reference therein). As a result, the problem of defining a stable and shared chronological structure that could facilitate correlations between Quaternary marine and continental deposits remains open.

The study of the continental Quaternary deposits in Italy after the mid-1950s past century took advantage of the advances in sedimentology, geomorphology, neotectonics, soil sciences, glaciology, biostratigraphy, palynology, isotope stratiography, tephrostratigraphy, and of various methods of numerical dating to improve its peculiar stratigraphic and correlation criteria.

The mounting evidence of multiple Pleistocene climatic cycles, interpretred from the study of deep-sea sediment cores, long lacustrine pollen, and loess/palaeosol successions, have led to the recognition of many more glaciations than the four of Penck & Brückner's scheme (Šibrava et al. 1986), while the ice-cores drilled in Greenland and Antarctica revealed the millennial scale climatic variability (Johnsen et al., 1992; EPICA Community Members, 2006). For all these reasons the continental deposits of the plains and of the intermontane basins in Italy could be studied and interpreted to decipher the complex events and the climate/environmental changes at the different time scales (e.g. Giaccio et al., 2019), as well as their neotectonics implications. The Neotectonic Map of Italy (Bosi, 1983, Fig. 1d) represented the first comprehensive attempt to synthetize the most recent (Plio-Quaternary) geodynamics of Italy; indeed, the entire territory turned out to have been affected by Quaternary tectonic activity (Galadini, 2004).

New exciting discoveries of human remains, frequently associated with lithic and bone artifacts, have been made throughout the last fifty years from Italian sites studied by geologists, palaeoanthropologists, palaeobotanists and palaeontologists. Of note, for example, is the skull from Ceprano, the skeleton from Altamura, and the remains from Isernia La Pineta, Cava Pompi, Visogliano, La Polledrara di Cecanibbio, and Casal de' Pazzi, together with the 5000 years old Ötzi mummy from the Niederjoch Glacier and the recently discovered nine Neanderthal individuals from the Guattari cave.

In the last decades, a number of fine-resolution, multiproxy (biological, geoarchaeological and geobiochemical) records have disentangled the role of human activities in triggering the ecological history of the Mediterranean and Alpine Quaternary, with a growing interest for the Holocene and contemporary dynamics. These studies take their first insights from the multiproxy record of archaeological deposits. However, for a quantitative evaluation of interacting man, climate, and ecological processes it is compulsory to refer to off-site contexts with natural and biological sedimentation, the variety of which are offered by the diversity of Mediterranean landscapes, including tree rings evidence. This has promoted several connected palaeoecological-archaeological research efforts, remarkably in inhabited lakes and mires (pile dwellings), coastal marine, lagoons, backswamp basins and marine caves nearby settlements (harbours, trade, fishing and ritual centres). Thanks to this flexible long-to-short term and transdisciplinary Quaternary concern it is now possible to compare past dynamics with contemporary changes, and to recognise baselines, thresholds and timelines of human impacts, in perspective to face an impending ecological transition.

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AUTHOR CONTRIBUTIONS

G.O. designed the overall structure of the paper and wrote section 3; M.R.P. wrote sections 2, 4 and 6; C.R. wrote section 5 and designed the Timeline (Fig. 1);

all authors wrote the foreword and the conclusive remarks, and contributed to the selection of the Timeline entries.

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Fig. 1 (a, b, c, d) - A graphic timeline depicting the main steps in the studies of Quaternary Science in Italy from the 18th to mid-20th century, with an abrigment of the milestones marking the last seventy years. some milestones have been provided by entries highlighted in bold.

Credits and references for images included in the figure:

Portraits of Quaternary scientists
Lyell, de Mortillet, Cocchi, Penck, Brückner, Du Pasquer - From Wikipedia - creative commons; Martins - From gallica.bnf.fr / Bibliothèque nationale de France; Sordelli, Venzo - Courtesy of Museo di Storia Naturale di Milano; Omboni, Paglia, Pirona - Courtesy Phaidra - Università di Padova; Scarabelli - Courtesy Stefano Marabini; Stoppani - Courtesy Centro Studi Abate Stoppani; Arduino - From Library of the Correo Museum, Venice; Dalla Fior - photo by Gino Tomasi, Courtesy MUSE - Museo delle Scienze di Trento. Biblioteca; Lona - Courtesy Nota Olfattiva, Parma; Issel - Courtesy Società Geologica d’Italia - Geoitaliani.it; Cita - Courtesy Library Digital Collections | UC San Diego Library (Cita) https://library.ucsd.edu/dc/object/bb3721209v.

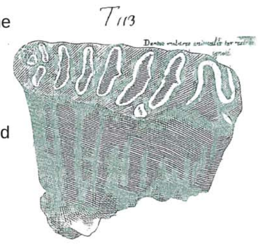
Fossils, maps and drawings
(1713) - Fossil Molar of Elephant (Cupani, 1713).
(1829) - *Prolagus sardous* (Wikipedia).
(1833) - Section Valle di Noto (Lyell, 1833).
(1846) - Geological Map of the Liguria Marittima (Pareto, 1846a).
(1850) - The Serra d’Ivrea glacial amphitheatre (Martins & Gastaldi, 1850).
(1854) - Key of Carta Geologica di Ravenna. (Scarabelli, 1854).
(1861) - Erratic block close to Frascarolo, Varese (Omboni, 1861b).
(1865) - Palate with molars of *Anancus arvernensis*, Villafranchian sequence of Asti (Wikipedia, Courtesy Museo Palaeontologico Territoriale dell’Astigiano).
(1872) - Reconstruction of the ancient glacier from Valle del Cacciatore, Apennines (De Lorenzo, 1892).
(1874) - Burial of *Homo sapiens* from Grotta dei Fanciulli, Balzi Rossi, Liguria (Catalogo Generale dei Beni Culturali, MiC - Ministero della Cultura).
(1894) - Succession of imbricated glacial-fluvioglacial complexes, a generalised section (Penck et al., 1894).
(1896) - *Rhododendron ponticum* fossil leaf from Piànico-Sèllere (Sordelli, 1896).
(1914) - *Thetystrombus latus* from Issel’s collection found in Cala Mosca, Sardinia, ex Museo Sardo di Geologia e Palaeontologia of the University of Cagliari (Romo Mulas, 2018) .
(1929) - Skull of *Homo neanderthalensis* from the Saccopastore cave, found by M. Grazioli in 1929 (Sergi, 1929) (Human Origins Program, Smithsonian Institution).
(1931-32) - Synthesis of postglacial pollen stratigraphy from the Piedmont area (Keller, 1931).
(1939) - (a) Skull of *Homo neanderthalensis* found in Grotta Guattari, S. Felice Circeo by Alberto Carlo Blanc in 1939 (Blanc, 1956). (b) Position of skull (a) in Grotta Guattari (Blanc, 1956).
(1950) - The middle part of the Leffe lake stratigraphy, Central Alps (Vialli, 1967).
(1953) - Logo of the IV INQUA Congress, Roma 1953 (restored and colored from https://www.inqua.org/)
(1954) - (a) Cover of “Quaternaria”, vol. 1, and (b) Editorial board of “Quaternaria”, vol. 1 (Courtesy Italo Biddittu).
(1956) - Cover of “Origine e sviluppo dei popoli cacciatori e raccoglitori” (Blanc, 1956).
(1978) - Cover of “Geografia Fisica e Dinamica Quaternaria” first issue (Courtesy GNGFDQ).
(1983) - Cover of the Neotectonic Map of Italy cased edition, published under the coordination of Carlo Bosi as a Research Package within a comprehensive Project on Geodynamics of Italy (“Progetto Finalizzato Geodinamica” promoted by the CNR) (Bosi, 1983).
(1988) - (a) First logo of the Italian Association for Quaternary Studies (AIQUA); (b) Current AIQUA logo; (c) Cover of “Il Quaternario” first issue (Courtesy AIQUA).
(1998) - The "Mandorlo" section described by Capraro et al. (2022), a novel stratigraphic profile encompassing the upper Piacenzian to lower Calabrian interval in the western sector of Monte San Nicola (Gela, Sicily), where the Global Stratotype Section and Point (GSSP) of the Gelasian Stage was defined (Photo courtesy of Sergio Bonomo).

A timeline of Quaternary Sciences in Italy

G. Orombelli, M.R. Palombo, C. Ravazzi. Page layout by R. Perego

1713

Francesco Cupani mentioned for the first time the presence of fossil elephant remains (i.e., dwarf elephants).



1760

Giovanni Arduino

Quaternary – Giovanni Arduino distinguished in “the sequence of strata composing the visible bark of the Earth… four general and subsequent orders”. The fourth and last order (“quarto ordine”) is a first mention to the “Quaternary”.

1808

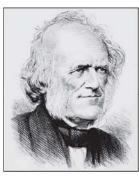
Filippo Nesti provided the first palaeontological description of proboscideans (mastodonts and elephants) from the Upper Valdarno Basin.

1829

Rudolf Wagner

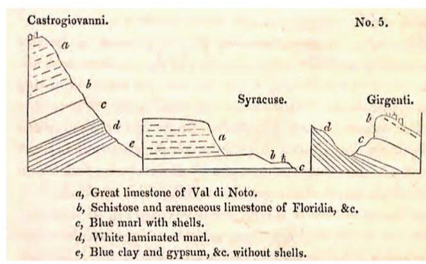
Rudolf Wagner created the first Sardinian endemic species, *Prolagus sardus*, from the remains of a giant ochotonid.

1833



Charles Lyell

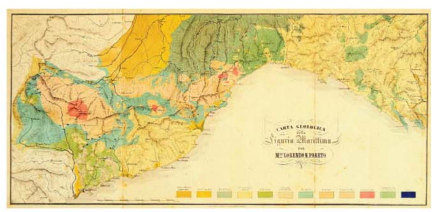
Pleistocene – Charles Lyell attributed the marine beds of Ischia and Val di Noto (Sicily) to the “Newer Pliocene”, in 1839 renamed “Pleistocene”, on the base of the most part of their fossils belonging to “species now inhabiting the Mediterranean”.



1846

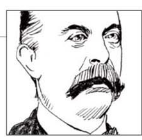
Lorenzo Pareto

Quaternary mapping – Lorenzo Pareto introduced the term Quaternary into the geological map of the Liguria Marittima.

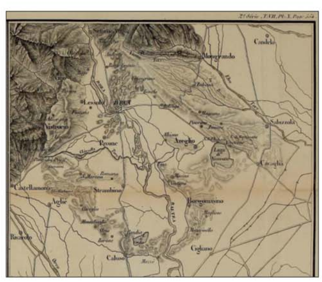


1850

Charles Frédéric Martins

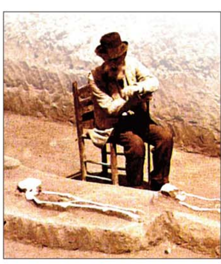


Bartolomeo Gastaldi



Glacial Theory – Charles Frédéric Martins and Bartolomeo Gastaldi published the first description of the “morainic amphitheatres” of Rivoli and Ivrea (Piedmont) recognizing their glacial origin.

1854



Giuseppe Scarabelli

In a geologic map of the province of Ravenna (Norther Italy), Giuseppe Scarabelli distinguished the Quaternary Period followed by the Anthropic Period, over the Pliocene subapennine marls and sands, anticipating the “ Neozoica Era “followed by the “Anthropozoic Era” introduced by Stoppani (1873).

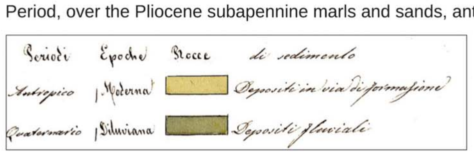


Fig. 1a - (see caption in previous page)

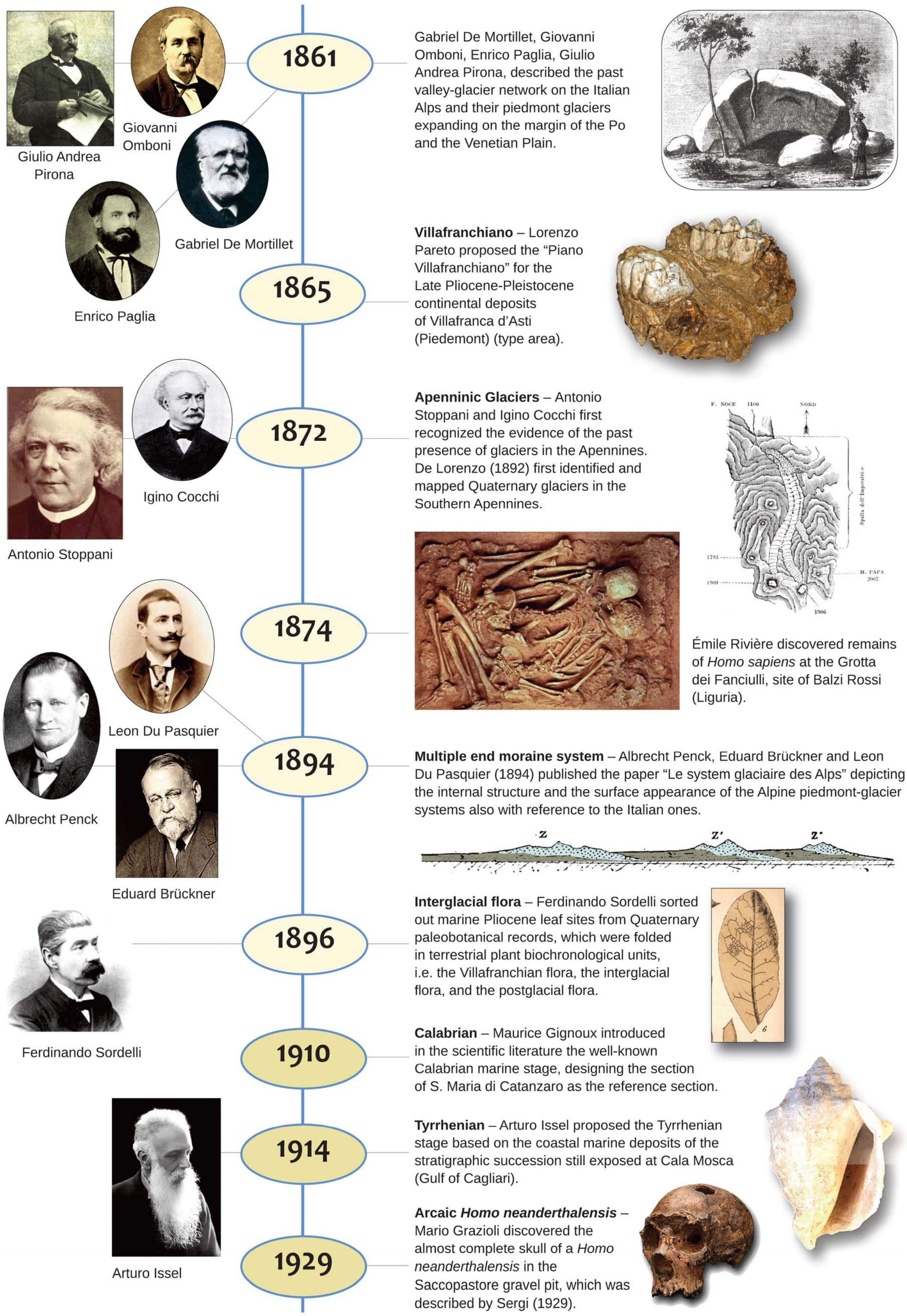
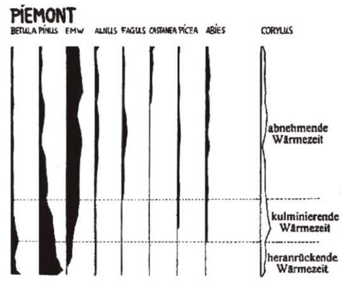


Fig. 1b - (continuation)

Giuseppe Dalla Fior

1931 - 1932

Stratigraphic palynology – Paul Keller and Giuseppe Dalla Fior obtained the first quantitative data on postglacial vegetation history in the Italian Alps through pollen records of peat deposits.



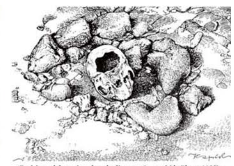
1935

Henri Breuil and Alberto Carlo Blanc found the incomplete skull of an adult male in the Saccopastore gravel pit.

Sergio Sergi Alberto Carlo Blanc

1939

Alberto Carlo Blanc discovered a well-preserved third Neanderthal skull in the Grotta Guattari cave (Mount Circeo).



Posizione del cranio sul suolo di grotta Guattari (da Blanc, 1956).

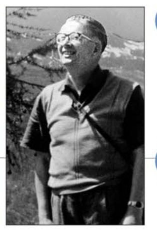
1930 - 1950

The Penck & Bruckner's four glaciation scheme was accepted in Italy and used in the geologic maps.

1948

Plio-Pleistocene boundary – At the International Geological Congress in London it was established that the Plio-Pleistocene boundary should be placed "at the horizon of the first indication of climatic deterioration in the Italian Neogene succession and should be based on changes in marine faunas".

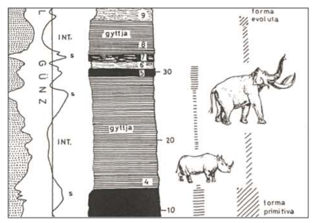
Fausto Lona

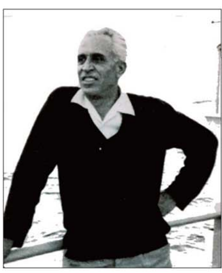


Sergio Venzo

1950

Fausto Lona and Sergio Venzo disentangled the structure of a complex sequence of Early Pleistocene climatic cycles in the Alps, based on the Leffe long pollen record. They also provide a first attempt of correlation with glacigenic units.





Raimondo Selli

1952

At the XIX International Geological Congress (Alger), the Plio-Pleistocene boundary occurrence was confirmed in the four Italian stratigraphical sections (Monte Mario, Rome - A.C. Blanc; Castell'Arquato, Piacenza - E. Di Napoli Alliata; Santerno, Imola - G. Ruggieri; and Val Musone, Ancona - R. Selli).

1953

IV INQUA Congress held in Rome-Pisa, the first INQUA Congress after the Second World War, "with Gian Alberto Blanc serving as president and inspiration". *https://www.inqua.org/about/history*

1954

Quaternaria – Publication of Quaternaria edited da Alberto Carlo Blanc for the Italian Institute of Human Paleontology in Rome, the first international scientific journal - with the name and entirely dedicated to Quaternary. The volume also includes one of the first releases on exploration of the Deep-sea Floor, with the oceanographic schooner "Vema", and a discussion of the forthcoming results on deep-sea stratigraphy by Emiliani with the isotopic method by Urey.

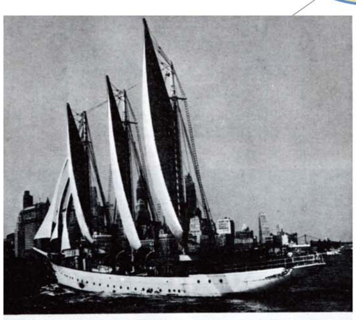


Fig. 14. — The three masted 202-foot schooner *Vema*, the floating oceanographic laboratory of the Lamont Geological Observatory, Columbia University.

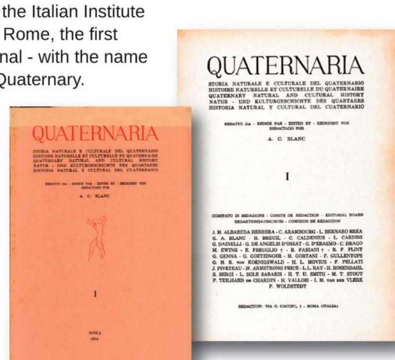
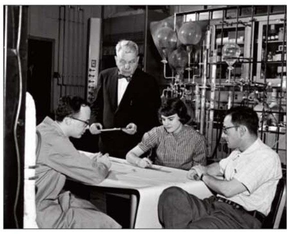


Fig. 1c - (continuation)

Harold Urey



Cesare Emiliani

1955

Marine isotopic stratigraphy – Cesare Emiliani with the paper "Pleistocene temperatures" kick-started the marine isotopic stratigraphy and attempted a correlation with the Milankovitch insolation curve, revised and confirmed by Hays, Imbrie and Shackleton (1976).

1956

Seminal book on Quaternary sciences – Alberto Carlo Blanc published "Origine e sviluppo dei popoli cacciatori e raccoglitori" a seminal book on Paleoanthropology and Quaternary.

The last forty years milestones

1960 to 1980

Defining Quaternary mappable units – New field surveys developed the Geological Map of Italy at 1:100,000 scale introducing a well established lithostratigraphic framework (132 sheets over a total of 277). Special attention was paid to mapping Quaternary deposits.

Augusto Azzaroli

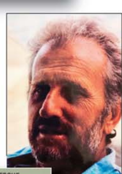
1970 - 1977

Faunal units – Augusto Azzaroli defined the "Faunal units" (biochronological units) on the basis of the mammalian species mainly from selected Italian Quaternary local faunal assemblages in an attempt to subdivide the "Villafranchian" mammal assemblages. He posed the base of the Quaternary Italian biochronology.

1978

AIQUA – The Italian Association for Quaternary Studies (AIQUA) was founded with the scope of developing the knowledge of the Quaternary and of its environmental and cultural heritage. *https://www.aiqua.it*

Publication of the journal "Geografia Fisica e Dinamica Quaternaria" by the Comitato Glaciologico Italiano, devoted to physical geography, glaciology, geomorphology and Quaternary Geology *http://gfdq.glaciologia.it*



Carlo Bosi

1983

Publication of Neotectonic Map of Italy (CNR) under the coordination of C. Bosi.

1988

Il Quaternario – Publication of the journal "Il Quaternario - Italian Journal of Quaternary Sciences" by AIQUA. The first issue provides an overview on the state-of-the art for each of the research fields of the Italian Quaternary.

1998

Gelasian GSSP – Domenico Rio and collaborators proposed the Gelasian as the last Pliocene Stage/Age (GSSP Global Boundary Stratotype Section and Point at Monte San Nicola, Sicily).

2009

The Quaternary System/Period and Pleistocene Series/Epoch were defined by the Gelasian GSSP, and the Neogene/Quaternary boundary aligned with Marine Isotope Stage (MIS) 103 and approximating the Gauss–Matuyama Chron boundary (2.58 Ma).

Maria Bianca Cita

2012

Maria Bianca Cita, Philip Gibbard, Martin Head and the Subcommission on Quaternary Stratigraphy formally defined the Vrica Section GSSP in Calabria for the base of the Calabrian Stage (2nd stage Pleistocene Series, Quaternary System).

AMQ – The official journal of the AIQUA took a new guise, and reached out to larger international audience, assuming the name of "Alpine and Mediterranean. Quaternary" *https://amq.aiqua.it/index.php/amq*

Fig. 1d - (continuation)

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