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ORIGINAL ARTICLE

A Whale in a Vineyard: Palaeontological Preparation and Education During the '*Brunella*' *Project*, a Large-Scale Conservation Effort Focused on a Pliocene Whale in Southern Tuscany, Italy

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Abstract

In 2007, a whale skeleton was found and excavated in Lower Pliocene sediments at Poggio alle Mura (southern Tuscany, central Italy). This partially complete skeleton is known by the nickname '*Brunella*'. The extracted blocks containing the fossil whale were deposited in a warehouse where they remained for nine years. A new project started in 2016 with the goal of (a) preparing and stabilising the whale bones, (b) studying its anatomy and relationships, and (c) developing educational activities to disseminate scientific information to local communities and tourists. In the years 2016–2019, the '*Brunella*' *Project* gave rise to an unprecedented number of activities in terms of scientific and educational efforts. The skeleton was micro-excavated, stabilised and prepared for exhibition; primary and secondary schools as well as university students were involved in educational activities both at the preparation laboratory and in their classrooms. University students were involved in a field school on palaeontological preparation that was active for three years (1 week per year); local populations were invited to visit the laboratory during special *Open days* where they were able to see palaeontologists working on the project, the whale and the palaeoecosystem in which it ended its life cycle; foreign tourists visited the laboratory and were involved in guided tours; social media were extensively used to disseminate results and advertise opportunities to visit the laboratory; a national TV channel screened a documentary on the whale and the project, disseminating a wealth of scientific results to hundreds of thousands of people. This project represents a *unicum* in Italy and can be seen as a prototype standard of an ideal process directed at preserving an important palaeontological specimen and, at the same time, enhancing the awareness and enthusiasm of local citizens for their local geoheritage.

Keywords Cetacea · Education · Field school · Mysticeti · Palaeontology · Pliocene · Preparation methods · Tourism

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Introduction

Palaeontology plays an important role in our collective imagination and, because of that, fossils may be used as a 'Trojan horse' to deliver scientific concepts related to both the evolution of life and the history of territories where charismatic fossils are found.

Dinosaurs gather the attention of almost everyone, even in Italy where dinosaur finds are rare (e.g. Dal Sasso 2003, 2005). This is testified by the unprecedented success of exhibitions focused on dinosaur palaeontology in Modena, Florence, Padova and Naples. However, exhibitions on alternative palaeontological subjects have had success too, suggesting that palaeontology per se is a relevant topic as a cultural attraction. In particular, three exhibitions of fossil cetaceans (primarily involving baleen whales) at Reggio Emilia, Florence and Asti have attracted surprisingly high numbers of visitors recently. The first of these exhibitions focused on a Pliocene right whale nicknamed '*Valentina*' (Bisconti et al. 2021a; Chicchi and Bisconti 2014; Chicchi and Scacchetti 2003); it was opened between 31 March and 30 June 2009 during which time it was attended by 9000 + visitors. The Natural History Museum of the Florence University opened a new Hall dedicated to the Pliocene Mediterranean Sea in 2016; there, a *c.* 10-m-long mysticete skeleton was displayed together with a sample of the molluscs that lived associated with the whale's remains (Cioppi 2014; Cioppi et al. 2011). This exhibition included a documentary and an explanation of the ecosystem that developed in association with the dead whale. This in turn was linked to concepts related to climate change. The Asti exhibition is titled *Balene preistoriche* (Prehistoric whales in English) and will be open from 30 September 2021 to 30 September 2022. In the first 9 months, *c.* 13,000 visitors attended to this exhibition.[1] These data underline the importance that fossil whales play in people's imagination and their capacity to attract visitors and school classes. Scientists and museum specialists have been able to deliver concepts related to the history of the relevant territories through these exhibitions thus enhancing local awareness of the geological and biological history of a region.

Based on the above observations, we anticipate that new finds of almost complete whale skeletons will be of interest to the general public, especially in the region where the fossils are found, and this is exactly the case with the skeleton of a Pliocene baleen whale discovered 15 years ago in southern Tuscany that is now known as the #whaleinavineyard and #brunellawhale on Twitter (Scotton et al. 2020).

In February 2007, a fossil skeleton of a baleen whale was discovered in the Pliocene of Poggio alle Mura (southern Tuscany), a locality in the territory of the Montalcino municipality (Siena province). This skeleton was found and excavated by a group of amateur palaeontologists (Gruppo AVIS Mineralogia e Paleontologia Scandicci) under the scientific direction of a technician from the University of Florence (M. Mazzini) (see Batini 2009 for the chronicle of the events). The specimen was discovered in a field close to the famous Brunello vineyards on land belonging to the Banfi S.r.l. company. During field operations, it was clear that a wide array of fossils was in close association with the skeleton, including shark teeth, mollusc shells, fossil wood and a diverse microfossil assemblage. Many international journals reported news about this fossil whale discovery to a global audience because of the location of the site in a field of an internationally renowned wine-maker company and because the timing of the discovery occurred when the new Brunello wine was to be presented to the public (e.g. Anonymous 2007; De Pretis 2007). The fossils were removed from the field after several months of excavation and were deposited within a warehouse close to the castle of Poggio alle Mura (Fig. 1) in the Banfi's property. The whale bears the number ICCD (Istituto Centrale per il Catalogo e la Documentazione) 09 00000001–18 and was nicknamed (e.g., *'Brunella'*) (Scotton et al. 2020).

This specimen remained in the warehouse for about nine years. In 2016, a renewed interest in this whale occurred as, under the co-ordination of Massimo Tarantini, the Tuscan Archaeological Superintendency (whose Italian name, at that time, was Soprintendenza Archeologica Toscana) launched a new exploratory project with the following goals: (i) to understand the physical conditions of the whale skeleton; (ii) to begin its preparation and consolidation; (iii) to develop a field school on fossil preparation and restoration in which university students could contribute to the preparation of the whale; (iv) to undertake a preliminary study of the specimen. The Istituto di Studi Archeo-antropologici (ISA), the company Banfi S.r.l., and Montalcino Municipality provided logistic and/or financial support and the project started with local news coverage. [2] [3]

In 2018, a new dedicated action (the '*Brunella*' *Project*), promoted and coordinated by new State heritage office in Siena (in the person of Massimo Tarantini and, later, Jacopo Tabolli), undertook actions to complete the preparation of

[1] https://www.torinofan.it/eventi/un-viaggio-nel-tempo-con-le-balene-preistoriche/; last access: 22 April 2022.

[2] http://www.montalcinonews.com/2016/11/progetto-brunella%E2%80%9C-la-balena-fossile-di-montalcino-scoperta-e-recuperata/, last access: 4 May 2022.

[3] http://www.montalcinonews.com/2017/02/con-%E2%80%9Cbrunella%E2%80%9D-torna-alla-luce-un-pezzo-di-storia-di-montalcino/, last access: 4 May 2022.

Fig. 1 The locality of the discovery of '*Brunella*'. **A** Italian peninsula with Tuscany in orange. **B** Tuscany outlined showing the location of Poggio alle Mura. **C** Close-up of Poggio alle Mura and near localities (scale bar equals 5 km). **D** Aerial view of the locality of the discovery (arrow and whale icon) and, on the background, the Poggio alle Mura castle. **E** A view of the vineyard castle at Poggio alle Mura

the specimen, to continue its scientific evaluation and to present this to the general public. The project was entirely funded by Banfi S.r.l. company[4] and represents a unique joint project of this kind between public and private entities in Italy.[5] Most of this story was published (see footnote 5) by Scotton et al. (2018, 2020) and part of the work carried out during this project was diffused, in popular terms, as a monthly online diary by the Tuscan Archaeological Superintendency,[6 7] as well as on the website of the Banfi Foundation.[8]

In the last few years, a strong, multidisciplinary effort was devoted to the scientific study of the whale, its associated biota and the discovery site. The earliest attempts to determine the age of this specimen revealed that the whale-bearing horizon was deposited in the middle Zanclean, *c.* 4.5–3.8 Ma (Avanzati 2018; Dominici et al. 2019). The age

[4] https://artbonus.gov.it/1261-cetaceo-fossile.html, last access: 29 April 2022.

[5] http://paleoitalia.org/media/attachments/news_news/221/la_conservazione_dei_beni_paleontologici_SPI.pdf, last access: 4 May 2022.

[6] http://www.sabap-siena.beniculturali.it/index.php?it/259/brunella-la-balena-di-montalcino, last access: 22 April 2022.

[7] http://www.sabap-siena.beniculturali.it/index.php?it/277/diari; last access: 22 april 2022.

[8] https://fondazionebanfi.it/it/progetto-brunella/; last access: 22 april 2022).

of the specimen is important as it documents that this whale is one of only a handful of Zanclean mysticetes from the Mediterranean.

Based on the morphology of the posterior end of the mandibular rami (including mandibular condyle faced posteriorly and reduced angular process), the ear bones (triangular anterior process of the periotic, transversely elongated pars cochlearis, ventral keel present in the tympanic bulla), the whale was preliminarily assigned to the Balaenopteridae family. Some morphological characters (especially the shape of the periotic) suggest that it may represent a new, basal species of balaenopterid, but the anatomical study is still in progress.

The age of ICCD 09 00000001–18, together with the extraordinary fossilisation of the associated biota, supports the hypothesis that this locality will be of high importance in the determination of (a) taxonomic placement, (b) trophic web, (c) environmental characters of the early Pliocene of the central Mediterranean area. In turn, this may provide crucial information about the recovery of the marine fauna and flora after the end of the Messinian Salinity Crisis and the re-establishment of fully marine conditions at the beginning of the Pliocene in the Mediterranean basin (Carnevale et al. 2019; Vai 2016; Roveri et al. 2014; Riforgiato et al. 2011). Wide-range taxonomic analyses were undertaken on the associated barnacles, nannoplankton, shark's teeth, trace fossils, fish otoliths, foraminifers, molluscs and the whale skeleton in order to better understand the characteristics of the palaeoecosystem that existed when they accumulated.

Three courses of the field school on fossil preparation and restoration were carried out involving students from many Italian and German universities. Workshops with local primary and secondary schools were undertaken to broadly disseminate the scientific results of the '*Brunella*' *Project*. Social media were extensively used to increase the visibility of the actions (Scotton et al. 2020). New hashtags (i.e. #brunellawhale, #pliocenerenaissance, #whaleinavineyard) were created, and others were used to disseminate the information about the activities at the warehouse during the project and to inform tourists and other people about possibilities to visit the preparation laboratory, and to talk to palaeontologists about the fossil whale and its palaeoecosystem (Scotton et al. 2020).

After 3 years of preparation work at the warehouse, '*Brunella*' become a well-known mysticete nickname in Italy and elsewhere, judging from the thousands visualisations of our posts in the social media (Scotton et al. 2020; see Education and tourism at the fossil excavation lab section in this paper) and is now part of the collective imagination of those living in southern Tuscany. The '*Brunella*' *Project* was described upon invitation to the first meeting of the Italian Palaeontological Society that focused on palaeontological preparation and preservation. This presentation was given at Florence in September 2019 as a case study that highlighted the positive interaction between governmental offices and private companies in conserving the remains, whilst ensuring the educational potential of this important fossil and its associated palaeoecosystem (see footnote 5).

Over the last five years, it became clear that '*Brunella*' acted as the focal point of an unprecedented number of activities in Italy as far as palaeontological heritage is concerned, and formed the basis for a multidisciplinary approach to reach wide-range scientific and educational results. The starting point of this process was, however, the preparation and stabilisation of the whale skeleton that suffered from remaining in a warehouse without climatic control for nine years. The bad effects of this stay were described in detail by Scotton et al. (2020); to cope with them represented one of the major methodological challenges of the entire project.

In this paper, we discuss (1) the methods that were used to prepare the whale skeleton and the associated fossils (in light of very little field information and after a long period in a warehouse without climatic controls), (2) the impact of the *'Brunella' Project* on tourism in the area and on the population of the relevant territory in southern Tuscany and (3) how an integrated use of social media, public conferences and *open days* allowed this whale to become part of the collective imagination of the populations in whose territory it was discovered. We conclude that this project is a useful prototype for geoheritage conservation in Italy and beyond.

Institutional Abbreviations

EGPPA, Ente di Gestione del Parco Paleontologico Astigiano, Asti; MSNUP, Museo di Storia Naturale dell'Università di Pisa, Calci; MGGC, Museo Geopaleontologico Giovanni Capellini, Bologna; MGPT, Museo Geopaleontologico dell'Università di Torino, Torino.

Geological and Palaeontological Context

Mediterranean Geodynamics in the Latest Neogene and Its Biotic Impact

In the Mediterranean region, the geological history of the last few million years was punctuated by three main extinction events at *c.* 5.96, 3.2–3.0 and 2.6–2.4 Ma (Carnevale et al. 2019; Landini and Sorbini 2005; Monegatti and Raffi 2001). The first event is related to the massive ecological changes that occurred at the end of the Miocene; it is known as Messinian Salinity Crisis (hereinafter, MSC) (Vai 2016; Roveri et al. 2014). The MSC has been recognised for many years (Hsü and Cita 1973) and is actively investigated by many research groups (Carnevale et al. 2019 and literature therein). The principal trigger of the biotic extinctions during

the MSC is thought to be a tectonic-driven partial or total desiccation of the Mediterranean that led to a massive species loss in *c.* 600 ky (Krijgsman et al. 1999). Even though the exact sequence of the tectonic and ecological steps that led to this large-scale impoverishment of the marine fauna is not completely known, it is clear that a crisis took place, and that the post-crisis cetacean fauna was taxonomically different from the pre-crisis, Late Miocene assemblage (e.g. Mas et al. 2018a, b; Bisconti 2010, Bisconti 2006; Bianucci and Landini 2002).

Dominici et al. (2019) documented that most of the Pliocene cetaceans from the Mediterranean are from the Piacenzian of Italy, and thus evidencing a gap in our knowledge about the earliest phases of cetacean colonisation of the basin after the end of the MSC. Only a few mysticete specimens are known from sediments with age constrained between 5.3 and 3.8 Ma: the holotype of *Balaena montalionis* Capellini, 1904 (MSNUP I-12357; Bisconti 2000, 2003), the Gorgognano balaenopterid (MGGC 21,813–21,833; Sarti and Lanzetti 2014), the Ca' Lunga (MGPT PU 13,810; Ormezzano and Lanzetti 2014) and Chiusano (EGPPA 217.13308; Bisconti et al. 2021b; Damarco 2014) specimens from Piedmont, and the whale from Poggio alle Mura that is the subject of the present work. This observation underlines the importance of ICCD 09 00000001–18 in the reconstruction of the recovery phases subsequent to the end of the MSC event.

Stratigraphy of Poggio alle Mura and Age of the Whale

The site of the discovery (Poggio alle Mura) is part of the Middle Ombrone Basin (hereinafter, MOB; Menacci et al. 2010; Bossio et al. 1991, 1994) that includes several places where numerous finds of shark's teeth, Pliocene whales, dolphins and sirenians have occurred over the years (e.g. Scotton et al. 2018; Bianucci et al. 2019; Sorbi et al. 2012; Danise 2010; Benvenuti et al. 2007; Sorbi and Vaiani 2007; see also footnote 5) (Fig. 1).

The stratigraphic section at Poggio alle Mura includes the uppermost Miocene sediments and a complete sequence encompassing almost the entire Lower Pliocene (Scotton et al. 2020; Avanzati 2018; Dominici et al. 2019). The Upper Miocene outcrops, represented by several lithologies, indicate a fluvial-lacustrine depositional environment. The earliest basal Pliocene deposition is not represented here because this area was submerged by the sea subsequently and marine Pliocene rests unconformably overlying the fluvio-lacustrine Miocene. Early-to-mid-Zanclean sediments include: (1) sands with large-sized molluscs (e.g. *Panopaea* sp. and *Pelecyora gigas* Lamarck, 1818) and lithodome-bearing rocks (Fig. 2A); (2) finer sands with a diversified mollusc assemblage (Fig. 2B); (3) clayey-sands with a shell bed dominated by *Helminthia vermicularis* Brocchi, 1814 and including the whale-bearing horizon (Fig. 2C); (4) clays with a poor fossil content (Scotton et al. 2020; Avanzati 2018; Dominici and Forli 2021; Dominici et al. 2019). This stratigraphic sequence shows a gradual increase of the depth throughout the Pliocene with parallel changes in the macro- and microfossil assemblages.

Following Bossio et al. (1994), two geological formations are recognised in the Poggio alle Mura area: (a) Conglomerati di Poggio ai Fichi and (b) Argille e argille sabbiose di Pod. Cavallini III, which were deposited in the Zanclean. Following the allostratigraphical concept, the Poggio alle Mura Zanclean is composed of SAS1s and SAS1a sub-synthema (Foglio 320,010—Regione Toscana—SITA Cartoteca). To better constrain the stratigraphic age of the whale-bearing horizon, molluscs, foraminifers, calcareous nannoplankton and magnetostratigraphy have been analysed. The mollusc fauna includes several well-preserved specimens of *Tethystrombus coronatus* Defrances, 1827 that become locally extinct *c.* 3 Ma in the Mediterranean basin (Monegatti and Raffi 2001), thus suggesting that the whale-bearing horizon was older than *c.* 3 Ma. Dominici et al. (2019) found that the *Helminthia* shell bed (i.e., the whale-bearing horizon) was deposited within the MPL2 zone of Cita (1975) which corresponds to an age interval of *c.* 5.1–4.45 Ma based on planktonic foraminifers. Avanzati (2018) provided a slightly different assessment based on preliminary analysis of calcareous nannofossils as he found that the whale-bearing, *Helminthia* shell bed was possibly deposited in the MNN13-MNN14/15 biozones as defined by Rio et al. (1990), corresponding to an age interval of *c.* 4.6–3.85 Ma. As a whole, the micropalaeontological content of the Pliocene outcrops at Poggio alle Mura supports the attribution of the whale-bearing, *Helminthia* shell bed to the Lower Pliocene and, more precisely, to the early-to-middle Zanclean. Quantitative calcareous plankton and magnetostratigraphic analysis, which are still in progress, are expected to tighten the relevant age interval.

Field Excavation

Field operations ceased in 2007 following removal of blocks of sediments that included the whale bones (Scotton et al. 2020). Paper and plaster jackets were used to protect the borders of the blocks and the surfaces in which the bones had been partially exposed (Fig. 3). The mandibular rami were removed from the field together with sediment blocks that were protected by plaster jackets and strengthened by steel tubes and wooden posts. The skull-bearing block and a large block including most of the cervical and thoracic vertebrae, two scapulae, a single humerus and many ribs were protected using dedicated wooden boxes strengthened by

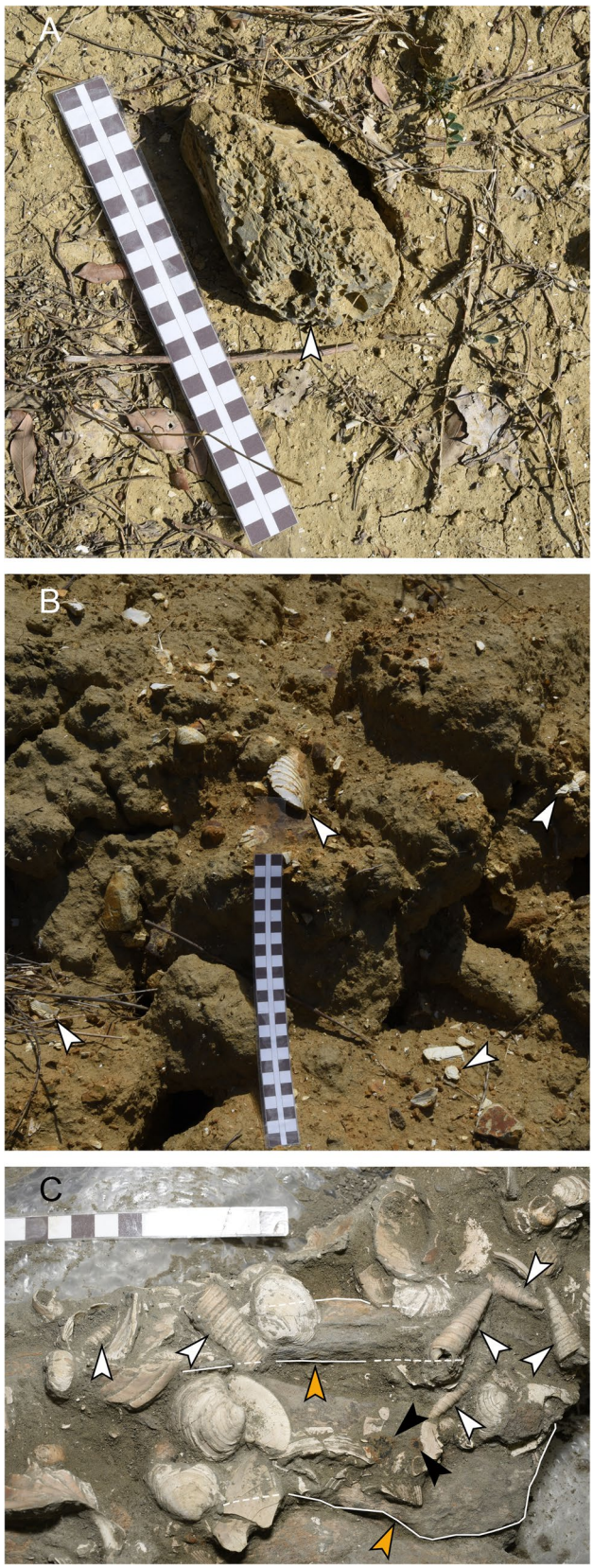


Fig. 2 Geological and palaeontological evidence from the site of the discovery. **A** Rock perforated by lithodomes. **B** A diverse mollusc assemblage (arrowheads indicate some of the numerous specimens in the field). **C** The *Haustator* shell bed corresponding to the whale-bearing horizon (white arrowhead indicate *Haustator* spp. specimens; black arrowheads indicate wood-bearing nodules; orange arrowheads and white lines indicate whale bones). Scale bars equal 25 cm in **A** and **B**, and 6 cm in **C**

steel tubes and covered by expanded polyurethane; in these blocks, the surface with the emerging bones was protected with paper and plaster jackets. The two large wooden boxes containing the skull and most of the postcranial skeleton were deposited upside-down in the warehouse. A number of shark's teeth found in close association to the whale bones, several mollusc shells, and a *c.* 30-cm-long fossilised fragment of wood were removed from the field and deposited in the warehouse together with the whale skeleton. Unfortunately, the relationships between these fossils and the whale bones were not recorded by the group that performed the excavation. Several pictures were taken during the field excavation and these were made available to the operators working in the '*Brunella*' *Project*. Only a few pictures represented the bones in an orthogonal way as most were taken from oblique points of view. Neither a map of bone dispersal, nor any information about the chemicals used in the field to pre-consolidate the specimen were made formally available to the operators of the '*Brunella*' *Project*. One of the present authors (M.B.) was present in the field for 2 days during which he took a few orthogonal pictures, sampled the sediment for micropalaeontological analyses, and described and measured the stratigraphic column at the excavation site (Scotton et al. 2020).

Micro-excavation and Preparation

Overview of the Fossil Preservation Before Preparation

Twenty-five blocks of sedimentary rock, containing whale bones and associated biota were recovered from the field and deposited in the warehouse at the Banfi S.r.l. facility in Poggio alle Mura (Scotton et al. 2020). Some of the blocks were covered by plaster jackets and paper; other blocks were not protected and the bones were visible. The covered blocks were opened by the operators of the '*Brunella*' *Project* immediately prior to the preparation process.

Once uncovered, the bones appeared dark brown, their surface details were hard to differentiate as a surface cuticle had developed on them. The bones were partly covered by the sediment, and mollusc shells were very abundant. The block including one of the mandibular rami showed a big fracture approximately at its mid-length (Fig. 4A–C). A

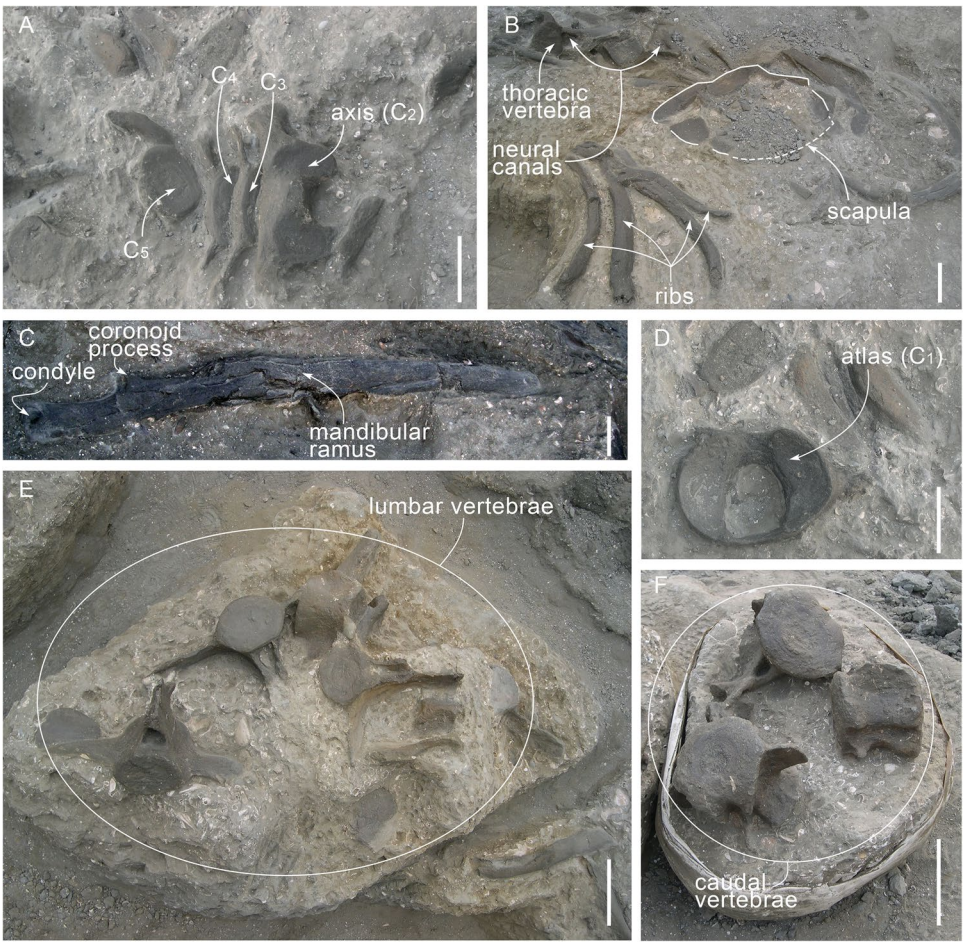


Fig. 3 Field photographs of the whale skeleton during the 2007 excavation. **A** Series of partially articulated cervical vertebrae including axis (2nd cervical vertebra: C_2), 3rd (C_3), 4th (C_4) and 5th (C_5). **B** Partial excavation of the ribcage including one scapula, one thoracic vertebra and several ribs. **C** Right mandibular ramus. **D** First cervical vertebra (atlas: C_1). **E** Group of lumbar vertebrae in a partially isolated block. **F** Group of caudal vertebrae surfacing from a completely isolated block whose lateral and inferior surfaces are protected by a plaster jacket. Scale bars equal 10 cm. Pictures by Michelangelo Bisconti

natural fault occurred in the largest block (Fig. 4D) and in another block (Fig. 4E).

The initial state of each block was recorded through pictures and by filling a standard printed form.

Preparation of the Whale Skeleton

Preparation operations began in 2016 and lasted until 2019. In 2007, most of the blocks had been deposited with the fossil-bearing surface up but the two largest blocks were deposited with the fossil-bearing surfaces down. These blocks included the skull and most of the ribcage. During the '*Brunella*' *Project*, both were re-oriented with the fossil-bearing surface up. In the case of the ribcage-bearing block, as the weight of the block was *c.* 4 t, specialised equipment and personnel was provided by the APICE company, Florence,[9] that was able to overturn the whole block without damaging the fossils still covered by paper, plaster jackets and polyurethane (Fig. 5A–C).

Once the blocks were ready, the plaster jackets were opened and the polyurethane was removed, the wooden boxes were opened and the operators micro-excavated the blocks to expose bone surfaces, to remove the old and oxidised stabiliser and to better consolidate the bones (Fig. 5D, E). Careful removal of sediment exposed a significant amount of skeletal remains that were previously obscured by the matrix. Almost all the thoracic vertebrae and most of the ribs were discovered through this process.

The oxidised stabiliser was mechanically removed as it had formed a cuticle over the bones. Different experiments with a new stabiliser were carried out to which dilution was the best solution for the whale and the associated molluscs. Stabilisers of various dilution were distributed over sampled bones for different periods of time in order to determine the best strategy to be adopted for stabilisation of the whole skeleton. The new stabiliser was made up by 50% acrylic microemulsion and 50% water and was applied by soft brushes.

The mandibular rami were carefully removed from the blocks and cleaned and stabilised. One of the blocks that originally included the mandibular rami was saved and prepared in order to preserve the original distribution of the

[9] https://www.apicescrl.it/it/, last access: 22 April 2022.

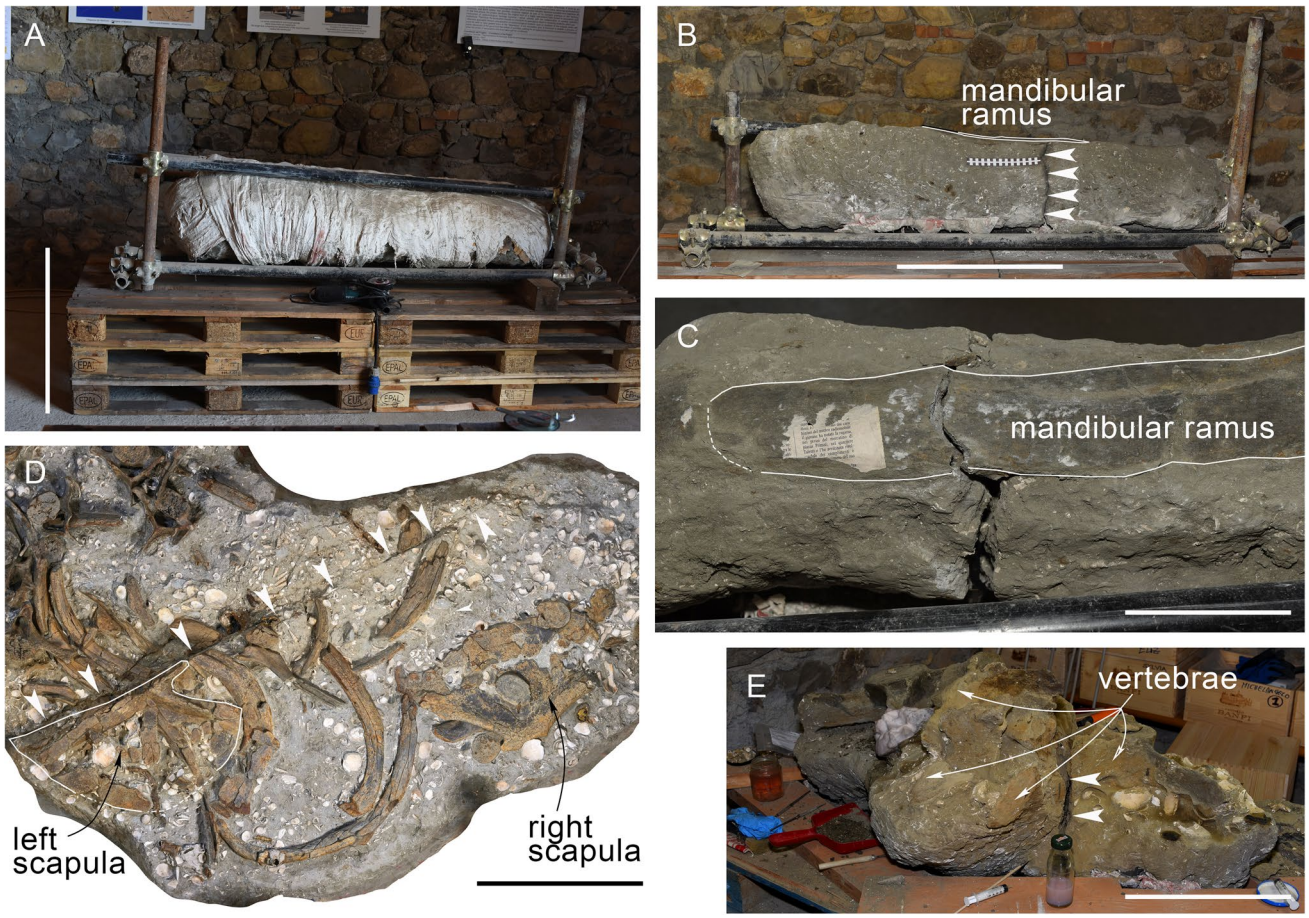


Fig. 4 Examples of preservation of the blocks. **A** The block including the left mandibular ramus was protected by a plaster jacket and paper interposed between the jacket and the bones; the whole block was reinforced by steel tubes (scale bar equals 50 cm). **B** The same block after the removal of the plaster jacket and the paper: note the fracture (white arrowheads) vertically crossing the whole block (scale bar equals 50 cm). **C** Close-up view of the same block showing that the fracture (big white arrowhead) affected the sediment and the whale bone (scale bar equals 10 cm). **D** View of the big block including most of the ribcage showing a fault (big white arrowheads) crossing the whole block (scale bar equals 50 cm). **E** Lateral view of a block including lumbar vertebrae and showing a fault (big white arrowheads; scale bar equals 50 cm)

mollusc shells under the mandible and in the stratigraphic column. Molluscs filled all the spaces within and between the bones probably also due to post mortem transport operated by bottom currents rather than growing attached to the bones. The shells closely associated to the bones were photographed and mapped before removal and careful storage.

The sediment removed during the preparation process was saved in its entirety for both micropalaeontological and palynological analysis. Thirty-one shark teeth were found in close association with the whale bones; these teeth are currently under study. All teeth but one were removed and carefully stored. The operators of the '*Brunella*' *Project* decided to leave a single shark tooth in the same position as it was found to show the close association between the teeth and the whale bones (Fig. 6). We tentatively suggest that the presence of these teeth is related to the shark feeding upon the whale carcass because shark bite marks were found in a number of bones. These bite marks suggest that many, if not all of the teeth, are in situ.

Preparation of the Invertebrate Fossils

The whale skeleton lies on a shell bed in such a way that hundreds of mollusc shells are visible in the blocks that were removed from the site. As the molluscs represent a prominent part of the fossil assemblage, their shells were prepared for study and exhibition following established scientific procedures. A number of mollusc shells were collected to test different chemical and mechanical properties of the fossils. All the specimens were prepared, curated and stored in dedicated boxes. During the preliminary analysis, the enveloping matrix in which the shells were embedded was weakened by

Fig. 5 Details of preparation of the whale skeleton and the associated biota. **A** The large box including the ribcage (*c.* 3.5 t in weight) in the original location in the warehouse as it was deposited after the 2007 excavation (note the polyurethane protecting the bones that is surfacing from the lower part of the box as indicated by the arrowheads). **B** The large box during rotation (arrowheads indicate the polyurethane covering the whale bones). **C** The large box after the rotation was almost completed. **D** One thoracic vertebra in the large box before preparation (arrowhead: note that the bone surface is barely observable; the black colour is due to the oxidisation of the 2007 stabiliser); the ellipses shows a surface apparently free of bones (scale bar equals 10 cm). **E** The same thoracic vertebra completely polished; the old stabiliser was removed and new stabiliser was distributed; note that the details of the bone surface are now perfectly visible; the ellipses shows that another vertebra was brought to light during the preparation of the previous one at a location where it was not previously noticed (scale bar equals 23 cm). **F** A group of mollusc shells including *Haustator* specimens with similar orientation broadly suggested by the arrow (scale bar equals 10 cm). **G** The same group was enclosed within canvas and stabiliser before being removed as a whole *ensemble*. **H** The same group deposited and protected within a dedicate box. **I** Exceptional preservation of a barnacle (probably *Concavus concavus*) on the transverse process of a whale vertebra (scale bar in cm). **J** Barnacle scars observed on a whale mandibular ramus (scale bar in cm)

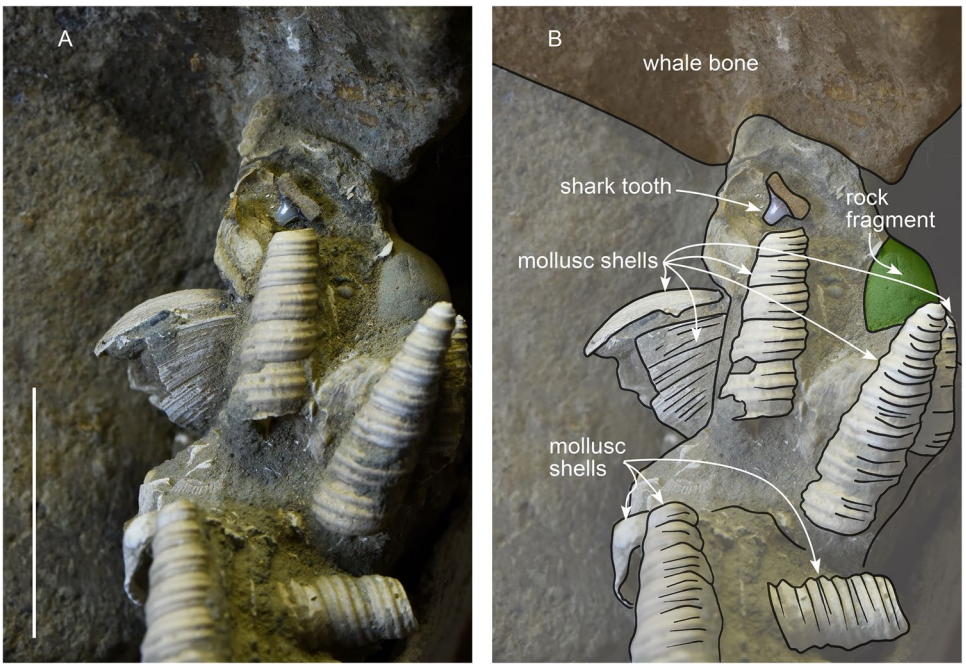


Fig. 6 Close-up view of a shark tooth in place at close distance to a skeletal element of '*Brunella*'. Note that several shells are present in the same area. **A** Photographic plate. **B** Interpretation. Scale bar in A equals 5 cm

a water + acetone mixture that was applied by a soft brush. Occasionally, the mixture was re-applied over a 24-h period to disaggregate the matrix and free the fossils.

As the shells were well-preserved, it was possible to clean these fossils revealing details of the surface ornamentation and permitting taxonomic identification. The preparation process was carried out with soft brushes and probes; any fractures generated during this process were repaired, maintaining the original shape of the shells and their original position in relation to the whale skeleton.

The block in which the left mandibular bone of the whale was preserved was carefully excavated after the removal of the ramus, exposing as many molluscs as possible and permitting analysis of their orientation along both horizontal and vertical axes. A number of nodules including plant remains were also discovered in association with the whale bones and were treated with specific methods (see next section). Both the whale mandibular rami were completely removed from the matrix and prepared; mollusc shells closely associated with the mandibular rami or directly adhering to the surface of bone were cleaned, photographed, and removed. Where possible, these shells were consolidated and stored in dedicated boxes with indication of their provenances.

On several occasions, we realised that groups of shells showed a preferential orientation of their long axes. This preferential orientation is interpreted as being caused by sea bottom or near bottom palaeocurrents. In most of these cases, we prepared, consolidated and left the molluscs in their original position to show this preferential orientation. For those mollusc shells that were removed, we isolated the specimens by excavating a trench of *c.* 1 cm all around the specimens and then the shells were enveloped under three strata of soft canvas after impregnation with a mixture of 50% acrylic microemulsion and 50% water. The microemulsion consolidated the molluscs and warranted a safe removal of whole groups of shells in their original position after that they were photographed in situ (Fig. 5F–H). The shells were then stored in dedicated boxes.

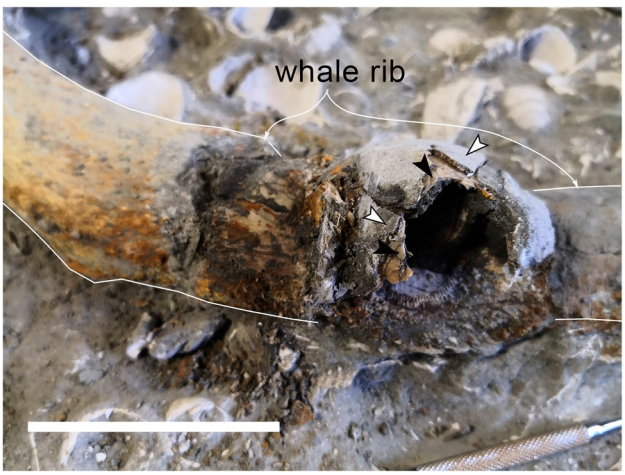


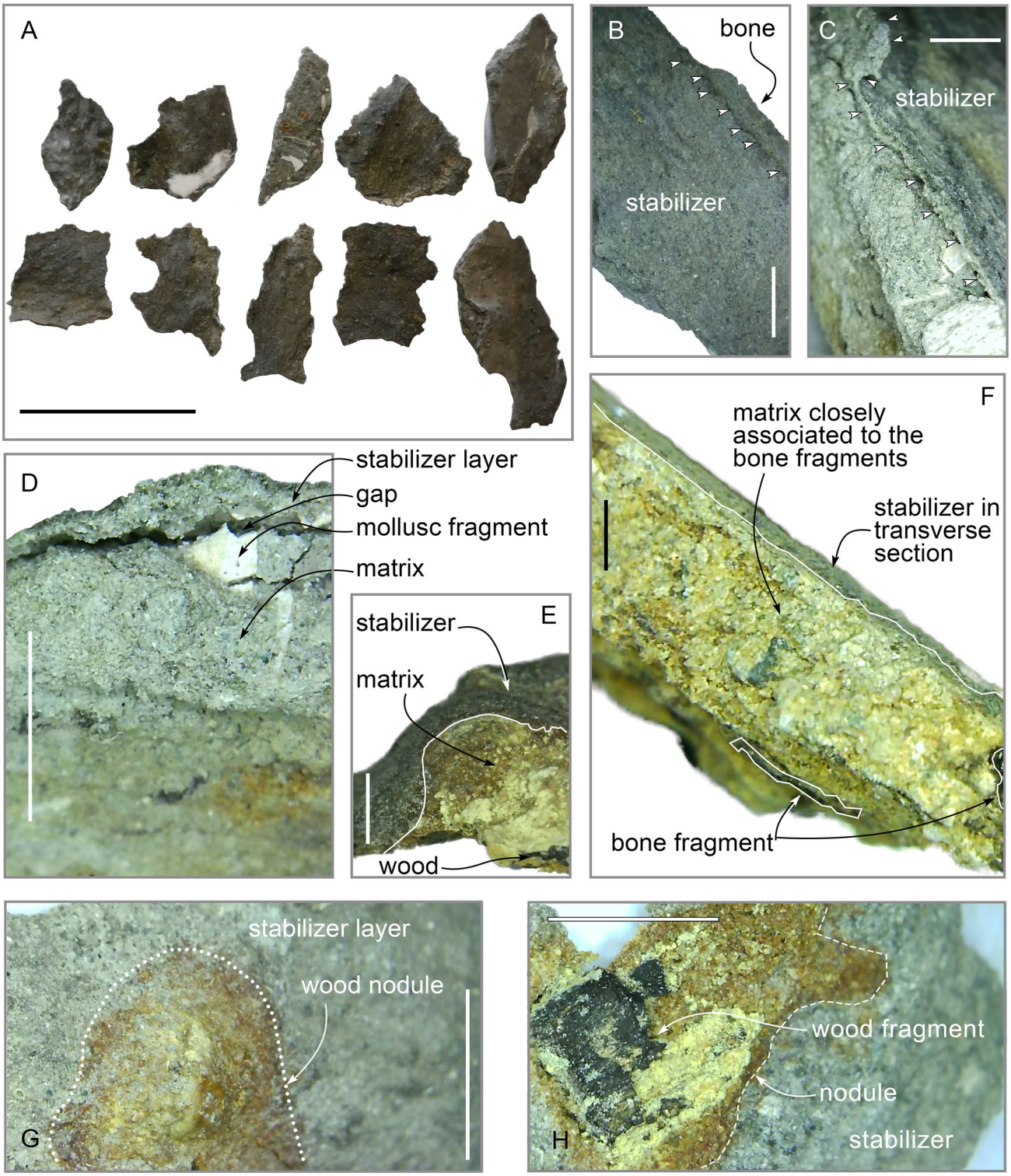
Fig. 7 Close-up view of a barnacle on a whale rib showing the cuticle formed by the 2007 stabiliser (white arrowhead) over the barnacle wall (black arrowhead). Scale bar equals 5 cm

Approximately 400 individual shells were labeled and photographed in the fossil-bearing blocks in addition to more than 200 specimens removed from the blocks. The taxonomic study of these shells is in progress, and we hope that most of them will be identified at species level in order to provide a high-resolution reconstruction of the malacological community represented in the biota associated to the whale skeleton.

Thirty-six barnacles and barnacle scars were recovered over or among the whale bones (Fig. 5I, J).

All of them were removed from matrix and stabilised with the same procedure adopted for the molluscs. In some cases, a cuticle formed by an old stabiliser was detected that could be dissolved in water (Fig. 7); this suggests that a vinyl stabiliser was used in the field in 2007 to preserve these specimens. The old stabiliser was dissolved and a new stabiliser was added to maintain the integrity of the specimens. A few specimens showed 3D preservation (Figs. 5I and 7). All specimens were studied and their taxonomy and ecological characters were assessed. Unfortunately, no opercular valves were found with these barnacles. They are nonetheless tentatively identified as *Concavus concavus* Bronn, 1831, which is known from rocks of this age in the Mediterranean. The barnacle scars are important as they show settlement

Fig. 8 Plant fossils found in close association with the whale bones. **A** Nodule including a wood fragment (white ellipses) found close to the axis and the other cervical vertebrae (scale bar equals 25 cm). **B** Close-up view of the same nodule (scale bar equals 10 cm). **C** A wood fragment (white arrowheads) found close to the right mandibular ramus (scale bar equals 10 cm). **D** A wood fragment (white arrowheads) found close to an indeterminate bone fragment (scale bar equals 10 cm). **E** Large wood fragment including a *Teredolites* trace fossil (scale bar equals 25 cm)



of barnacle cyprids (larvae) after the whale had died, had settled to the bottom and had been stripped of soft tissue. This means that the barnacles did not accumulate around the whale bones in the same manner as most of the mollusc shells, the latter being introduced as mostly disarticulated shells by bottom currents and trapped around the skeleton.

Preparation of Palaeobotanical Specimens

During the preparation, several palaeobotanical specimens were found in the block sections and on the surface; these consist of nodules enveloping wood fragments and partial branches of trees (Fig. 8A–D). All the sampled specimens

◂**Fig. 9** Analysis of the old stabiliser by microscopy. **A** Fragments of cuticle formed by the old stabiliser (scale bar equals 5 cm) as seen from above. **B** A specimen observed from above showing the sharp edge of the stabiliser layer (indicated by the arrowheads) that allows that lies along the border between the stabiliser and fossil bone (scale bar equals 5 mm). **C** Three-quarters view of a specimen showing the stabiliser layer looking like paper indicated by the arrowheads (scale bar equals 5 mm). **D** Sequence through of a specimen showing the thick layer of the old stabiliser, the top of which is separated from the sediment surface by a gap (scale bar equals 5 mm). **E** Three-quarters view of a specimen in which sediment and old stabiliser are tightly joined but the stabiliser layer is still evident (scale bar equals 5 mm). **F** A specimen showing the thin layer of the old stabiliser tightly bonded with the sediment (yellow) covering the bone fragments (scale bar equals 5 mm). **G** Specimen, as observed from above, showing inconsistent distribution of the old stabiliser demonstrated by the presence of an uncovered wooden nodule emerging from the stabiliser layer (scale bar equals 5 mm). **H** The same specimen as in **G** as seen from below (scale bar equals 5 mm)

were mapped and their relationships with the whale bones were recorded. Micro-excavation of the nodules was performed by excavating around each specimen at a distance of 5 mm from the external surface of each nodule. The excavation was then expanded and deepened mechanically excavation to detach the nodule. Wood fragments were prepared under a magnification lens using soft brushes. In the case in which the wood fragment appeared particularly fragile and fragmented, we applied several highly diluted doses of the stabilising chemical, allowing full penetration of the preservative within the wood. Three layers of a soft canvas were then applied over the pre-consolidated fragments to maintain integrity during the removal. The removal occurred on specimens following visual and tactile inspections that confirmed that the specimen was fully consolidated. After the detachment, the canvas was carefully removed, and the wood was additionally consolidated by application of the stabiliser by using a soft brush. The specimens were then stored in dedicated boxes. Matrix from the blocks originally removed from the field are stored in dedicated boxes to allow future analyses of pollens and dinoflagellate cysts.

A single, 30-cm-long fragment of Pliocene wood was deposited in the warehouse from the whale excavation of 2007 (Fig. 8E). This specimen bears a *Teredolites* trace fossil. During the 9 years of its storage within the warehouse, cracks appeared in the wood fragment, breaking it into several parts. The specimen was cleaned, wrapped in aluminium foil, closed within a plaster jacket to preserve it from further degeneration. This kept all the fragments together and saved the sample from variations in temperature and humidity. This conservative approach was the only procedure followed to stop the natural degradation of the specimen. Additional actions are now urgently required to stabilise this Pliocene wood fragment and to stop further degradation.

Sampling

Apart from the vertebrate, mollusc and barnacle specimens described above, we removed *c.* 225 kg of matrix during the preparation of remains from the site. All the matrix removed during the preparation of the skeleton was stored; sediment samples from areas adjacent to the discovery site and from higher and lower levels in the stratigraphic column were taken in 2007 by one of the present authors (M.B.). The matrix was subdivided into 84 bags and underwent analysis for fish otoliths and microfossils. This work is in progress with 1930 Pliocene fish otoliths currently recovered. All the barnacles, barnacle scars and shark teeth were photographed, labeled, and reported in the map of distribution of the whale bones and photographed. Then, all the specimens were submitted for taxonomic and palaeoecological analyses. One large (*c.* 25 mm in maximum length) sea urchin spine was detected in the matrix close to the whale bones. It was mapped, prepared, removed and deposited in a dedicated box. Thousands of sea urchin spines are present in the matrix but their preservation is generally poor.

Reconstruction of the Original Deposition of the Whale Bones

Several pictures from the field excavation were provided by the volunteers and a limited number were taken by one of us when in the field (M.B.). Almost all the pictures represent the exposed bones in oblique ways. Only a very general map was produced (by M.B.) during the field work in 2007 outlining the external perimeter of the bone distribution and relationship of the skull and mandibular rami with respect to the ribcage and the disarticulated lumbar and caudal vertebrae and forelimb elements. A few pictures were taken in the field once the blocks had been partly excavated so that it was possible to determine the original disposition of the blocks now in the warehouse. Once the blocks in the pictures were identified, the photographs were treated with the perspective correction instrument of Adobe Lightroom Classic that allowed changing the point of view and transformed oblique pictures into orthogonal ones. In doing that, the programme generates deformations in the objects represented in the picture in the following way: horizontal pictures are deformed with the distances along the vertical axis being changed by the transformation algorithm although the distances along the horizontal axis are not. In this way, and after treating a number of pictures with this method, we obtained several reasonably correct distances between the blocks and, therefore, it was possible to place most of the blocks in the correct position within a map of bone dispersal. To our knowledge, this is the first time that this method is used to the present scope.

Analyses of the Chemicals Used in 2007

The Old Stabiliser

The stabiliser used in 2007 was the Paraloid B72. This information was provided to the operators of the '*Brunella*' *Project* by the volunteers of the 2007 excavation. No information about the dilution was provided by the volunteers therefore we did not know the exact concentration of the stabiliser used during the field work. What we observed was that the dilution was insufficient to penetrate the bones, rather it formed a sort of an external cuticle that could be removed using a scalpel during preparation. It is thus very likely that the concentration of the stabiliser used during the field work was too high to penetrate the bones. Soon, the operators became aware that the internal structures of the whale bones were not stabilised and were prone to disintegrate if handled without a new and more efficient stabilisation procedure.

Fragments of the old stabiliser were removed during the preparation of the skeleton (Fig. 9A) and were observed by a RoHS wi-fi digital microscope able to provide HD images (1980 × 1080 pixel). The stabiliser layer was easily identified as it had a distinct colour and density compared to the sediment, fossil bone and fossil wood; if observed from above, the stabiliser layer showed sharp edges at its lateral terminations (Fig. 9B). In cases, it could be easily removed like a piece of adhesive paper tape (Fig. 9C).

The stabiliser was non-homogeneously distributed during the field operations forming anything from a thin cuticle to a thick layer at different locations. In the cases in which the stabiliser formed a thick layer, a gap developed between the stabiliser and the sediment underneath (Fig. 9D), so that the stabiliser formed a raised layer that was not in contact with the sediment (including mollusc, bone, and wood fragments) thereby not providing its preservation capacity to the fossils. Likely, humidity was trapped between the raised stabiliser layer and the sediment surface and this probably decreased the chemical stability of the fossil bones leading to the damage to the internal structures described above.

In the cases in which the stabiliser formed a thin cuticle, it remained tightly joined with the sediment (including mollusc, bone and wood fragments) (Fig. 9E, F) but it can still be observed as a separate layer from the sediment. It is unclear whether in these cases it was able or not to preserve the internal structures of the bones. Certainly, the stabiliser distributed during the field operations prevented the dispersion of fragments generated by the natural disintegration of the fossil specimens but it was unable to prevent the destruction of at least part of the internal structures of the skeleton. In cases, the stabiliser had not completely covered the specimens (Fig. 9G, H).

The Polyurethane

The original polyurethane was chemically analysed by a private company (Geochim S.a.S., Loc. Sigillo, Perugia province) who provided a report (Rapporto di Prova 64,736, Rif. Interno R.I. 16,605, 2 July 2019) including all the methodologies used. The analyses found presence of antimony, arsenic, mercury, lead, aromatic chemicals in quantities that were tolerated by the Italian law but that were sufficiently high to impose the adoption of protection masks, glasses and body suites for the operators of the '*Brunella*' *Project*. Moreover, the results of the analyses strongly suggested that we ask a specialised company to remove the polyurethane from the big box including the ribcage and to clean the whole warehouse. The work made by this company was supervised by the operators of the '*Brunella*' *Project* to prevent accidental damage to the fossils.

Conservation Results of the '*Brunella*' *Project*

Our subsequent preparation and stabilisation of the whale skeleton found in Poggio alle Mura was successful. The whole skeleton was micro-excavated, prepared and stabilised. All the removed sediment was stored for future analyses. In the process, further portions of the skeleton were exposed that previously had been hidden by the sediment. Tens of shark teeth, barnacles, barnacle scars, trace fossils, wood fragments, and hundreds of mollusc shells were discovered, prepared and stabilised. The sediment was then filtered and treated in search for fish otoliths, sea urchin fragments and other fish remains. Part of the sediment was preserved for further palaeobotanical analyses. The map of the original distribution of the whale bones was digitally reconstructed and is now shown in Fig. 10. This map is a key instrument to understand aspects of the taphonomy of the specimen and will provide students and visitors with useful information about the destiny of this whale after death.

The old and oxidised stabiliser was removed and new stabiliser was distributed that maintained the original colours of the fossil bones and allowed the detailed analysis of the bone surface—this being fundamental in the search for trace fossils potentially revealing the existence of a whale fall palaeocommunity. Aspects of the taphonomy of 'Brunella' have been provided by Santagati et al. (2021) but additional work is needed to better decipher the wealth of the trace fossils assemblage found in the whale bones that are still under study.

Additional documentation was gathered during the project. Two 3D renderings of the skull and the ribcage of the whale (Fig. 11) were undertaken and a wide-range, aerial photographic documentation of the fossil site and the surrounding areas was performed (Fig. 1D). Moreover, a cast

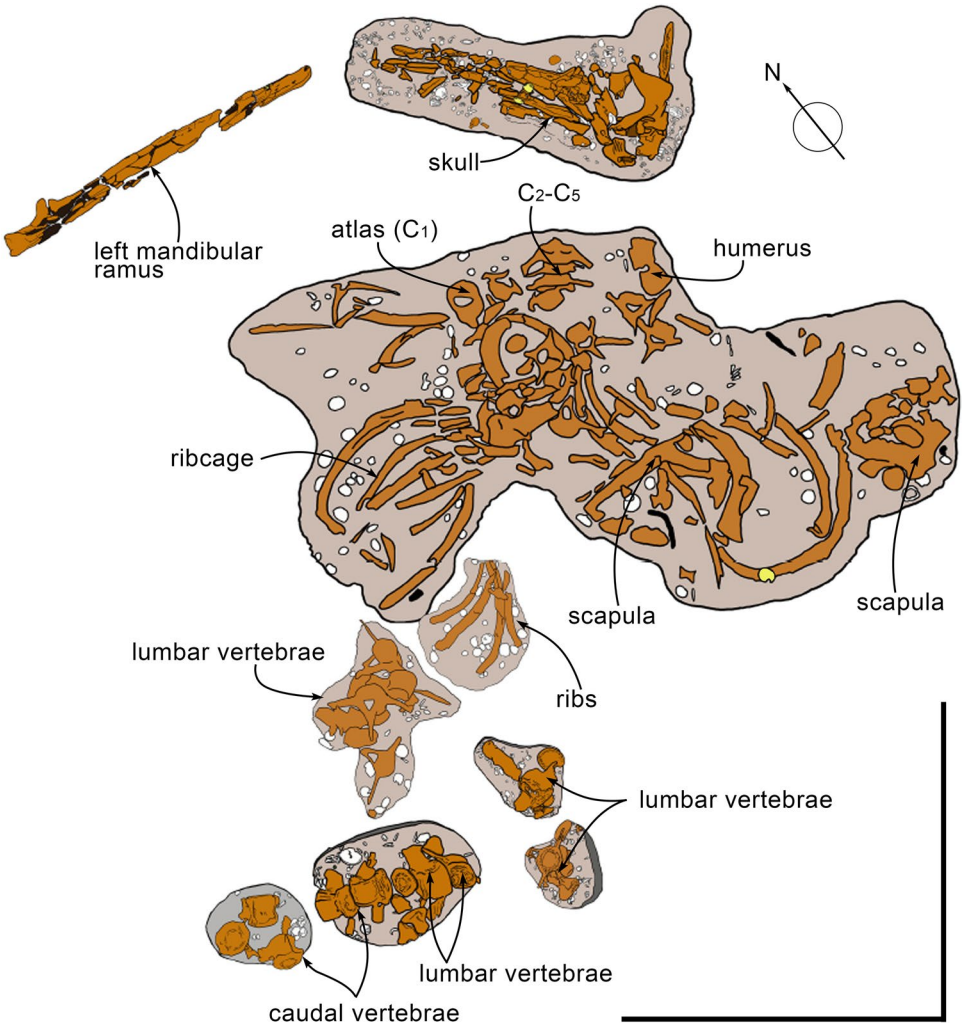


Fig. 10 The skeleton of '*Brunella*' as reconstructed from the present work. The largest blocks in their inferred position at fossilisation with many whale bones exposed. Black spots represent wood fragments. Yellow spots represent barnacles. Scale bar equals 1 m. Note that the skeleton is largely disarticulated and crushed; the peculiar arrangement of the bone distribution is the key for a narrative about the history of this whale from death to burial

of the skull, as exposed on the surface of the corresponding block, was undertaken, opening the possibility of a new project on the complete extraction and preparation of the skull without losing information on its original disposition.

Education and Tourism at the Whale Preparation Laboratory

All the operations directed at the preparation of '*Brunella*' were planned to incorporate educational activities for a wide spectrum of potential public. The scientific work at the site provided a constant flow of information that was used to assemble a narrative of the history of the whale from death to burial in the context of the palaeoecological reconstruction.

Formal Education

The operators of the '*Brunella*' *Project* developed a *portfolio* of educational laboratories that were shown to the schools of the southern Tuscany during a conference in the historical theatre of Montalcino and by sending brochures via mail. The conference was attended by *c.* 10 school classes from the elementary schools of the territory with *c.* 200 students very active in asking numerous questions to the scientific director of the '*Brunella*' *Project* who was at their disposal for more than two hours (Scotton et al. 2020). Conferences in the elementary schools were then performed together with combined lessons-and-laboratory experiences at the warehouse in Poggio alle Mura where the '*Brunella*' *Project* was being carried out. Lessons included aspects of the geological and palaeoecological history of southern Tuscany, the information that fossils can reveal about the history of the territory, the mollusc shells associated to the whale skeleton, the characteristics of

Fig. 11 A photogrammetric representation of the skull of '*Brunella*' in anterodorsal view

the mysticete whales and the taphonomic history of '*Brunella*'. The participation of young students was enthusiastic. Boys and girls were very active within their classrooms and when visiting the laboratory where '*Brunella*' was being prepared. They used the microscope to explore the sediment at their disposal and were excited when observing small-sized shark teeth or exquisitely preserved, tiny mollusc shells.

Two high school classes were involved in a project funded by the Italian Government (PON, Candidatura N. 1183 4427, 2 May 2017[10]) on the development of communicative skills concerning the scientific concepts (whale anatomy and evolution, palaeoecology at the discovery site in Poggio alle Mura, preparation methodology) related to the '*Brunella*' *Project* and jointly carried out by the operators of the '*Brunella*' *Project* and the teachers of the involved high school (Fig. 12A). The students were guided through field activities (surface exploration at the discovery site, sampling of Pliocene molluscs from different stratigraphic settings, conservation works related to the molluscs) in order to give them the possibility to perform first-hand palaeontological experiences. Subsequently, they were asked to write down a short essay and a blog on the '*Brunella*' *Project* with data that they were able to collect. The data included pictures and videos made during the preparation process, interviews with the operators and general information on geology and palaeontology at the site. The students worked in small groups under a peer-to-peer approach; they used their own devices (smartphones and tablets) and were allowed to organise their work as they preferred by using digital applications of their choice; the operators of the '*Brunella*' *Project* and the teachers involved in the project supervised the work and provided help whenever necessary. The participation of the students was variable revealing that Palaeontology is not interesting for all the young people per se. Many students were interested in (a) learning new communicative techniques, (b) practical activities related to the project, and (c) realisation of the blog by using technological instruments. Some students were very interested in the field work directed at collecting, cleaning and cataloguing fossil shells. Additional pictures of this project can be viewed on the website of the Tuscan Archaeological Superintendency.[11]

University students from Geology and Palaeontology courses at the University of Florence and students from the Università per Stranieri (International Athenaeum) of Siena came to the warehouse and observed the work of the operators during the preparation of the whale and the other associated fossils. They were taught the history of the project and relevant activities, along with the geological and palaeontological importance of the find and its bearing in the international debate about the evolution of baleen whales and the Messinian Salinity Crisis.

A field school on preparation and conservation of palaeontological specimens was active from 2016 to 2019. University, doctoral and postdoctoral students attended this school from many different universities in Italy and Germany. The students received lessons from numerous professors from the Universities of Siena, Pisa, Florence, the Scuola Normale Superiore (Pisa), the Museo di Storia Naturale di Milano, and the Istituto di Studi Archeo-antropologici. A wide range of subjects were covered: geology and stratigraphy of southern Tuscany, whale anatomy and evolution, mollusc evolution, whale taphonomy and whale fall ecology, museum studies, geopalaeontological educational strategies and preparation techniques (Fig. 12B). The students were also able to directly participate into the preparation of '*Brunella*' by joining the operators in the laboratory (Fig. 12C). They were supervised and taught by the preparator head of the '*Brunella*' *Project* and by all the other operators and had constant feedback with professionals. They were also trained in working in the field at the location of the discovery where they studied the stratigraphic section at

[10] https://www.istruzione.it/pon/avviso_patrimonio-artistico.html, last access: 27 April 2022.

[11] http://www.sabap-siena.beniculturali.it/index.php?it/277/diari, last accessed: 28 April 2022.

Fig. 12 Formal and non-formal education at the laboratory. **A** Students from a high school working on a project about scientific communication based upon their field experiences on the taxonomy of fossil molluscs. **B** A typical lesson during the field school in palaeontological preparation; here the head preparator (R.S.) teaches preparation techniques. **C** Students of the field school working on the preparation of part of the skeleton of the Pliocene whale. **D** Visitors during a guided tour by an operator (M.B.) during an *Open lab* event. **E** Children visiting the laboratory with their families during the *Open lab* events and asking questions to an operator (M.B.)

the site, the different stratigraphic levels observed in the field and the fossil record of the territory. Pictures of the field school were published by Scotton et al. (2020) and can be viewed in the website of the Banfi Foundation.[12]

Social Palaeontology: a Key Component of Citizen Science Activities

The definition of Social Palaeontology comes from Spanish experiences directed at disclosing the educational potential of Palaeontology at all levels (Torices et al. 2004; Castilla Cañamero et al. 2006). The '*Brunella*' *Project* aimed to accomplish this goal by developing different activities involving a broad spectrum of the community. Apart from the formal educational projects dedicated to schools and universities, additional activities were developed that attracted a diverse audience at the laboratory. In particular, considerable success was attained by the *Open Lab* (*Cantiere aperto* in Italian) at the warehouse where the '*Brunella*' *Project* was being carried out. The laboratory was opened on two occasions and more than 700 visitors came to the warehouse, visited the laboratory and observed '*Brunella*' and its palaeoecosystem in guided tours provided by the project operators (Fig. 12D, E). Visitors came from the whole of southern Tuscany (Grosseto and Siena provinces) and made tours in small groups in which they could easily and informally interact with the operators by making questions and freely moving through the laboratory. Some teachers brought their students to the laboratory during these days too.

Part of the advertisement for the *Open Lab* was successfully made through social media (such as Facebook and Twitter). The 29 tweets published by the scientific director of the project (M.B.) received 39,371 views, a result that was well beyond the expectations. Twitter was a useful way to inform tourists from all over the world about the existence of the laboratory and the fossil whale. Poggio alle Mura includes a beautiful castle, a museum of historical and archaeological wine bottles, a restaurant and a wine shop hold by Banfi S.r.l. company and is thus already an attractive centre for international tourists. The operators received many tourists at the laboratory that came there by chance their primary objective being a visit to the Banfi facilities and wine shop. In those cases, the operators stimulated tourists' attention by placement of blackboards just outside the laboratory with nice sketches and statements about '*Brunella*' (Scotton et al. 2020). These blackboards attracted many visitors to the laboratory.

After two years, the '*Brunella*' *Project* came to an end. The laboratory was visited by more than 2000 visitors and, in many cases, these people (especially non-Italian ones) said that they had received information about '*Brunella*' from Twitter. Tourists, in small groups, visited the laboratory in guided tours with the project operators providing a commentary in Italian and English. No fee was required for the visits of the *Open Lab* days and for the visits of occasional tourists.

After the formal end of the '*Brunella*' *Project*, a public conference was given at the Accademia dei Fisiocritici in Siena. This is a historical and prestigious institution in

[12] https://fondazionebanfi.it/en/brunella-project/archeobioschool.php, last accessed: 28 April 2022.

which scientists, humanists and non-specialised people are welcome to attend educational programmes and conferences of cultural interest. Many people attended the conference in which the project was explained.

In the end, a documentary on '*Brunella*' was produced by the Italian National Television (RAI 1) by one of the most celebrated scientific journalists in Italy (Alberto Angela). The documentary was shown on an important TV programme devoted to science popularisation and can be freely watched online.[13] The programme was watched by 726,000 people representing a share of 8.23%.[14]

Future Perspectives

The SARS-CoV-2 pandemic halted further development of the '*Brunella*' *Project* for more than 2 years. In retrospect, the work that has been done at the laboratory in the warehouse of Poggio alle Mura was unique for several respects. Its special characteristics included: (a) a joint co-operative effort between a governmental agency and a private company; (b) funding almost completely sourced privately; (c) wide range scientific investigations involving conservation science, geology, stratigraphy, vertebrate and invertebrate palaeontology, micropalaeontology, palaeobotany, and palaeoichnology; (d) broad-scale dissemination of preliminary results and work in progress to a wide audience including school classes and university students, tourists and non-specialised, local public. The educational activities carried out at the laboratory worked well and represented an exploration of the educational potential of the site. The fossil whale represents an exceptional "Trojan horse" enabling operators to deliver a wealth of scientific concepts related to the geological history and the palaeontological content of the territory where the whale was found.

Now that the '*Brunella*' *Project* is formally closed, it is to be hoped that an exhibition will be established to permanently illustrate the scientific outputs resulting from the anatomical and phylogenetic analysis of this Pliocene whale, and the study of the palaeoecosystem where it ended its life cycle. A museum concept for '*Brunella*' is under study for the development of a permanent exhibition at Poggio alle Mura. Hopefully, when the current pandemic ends, '*Brunella*' and its palaeoecosystem will be once again a centre of geoheritage interest for the whole central Mediterranean basin.

[13] https://www.youtube.com/watch?v=viOxXpEG0lA; last access: 4 May 2022.

[14] https://it.wikipedia.org/wiki/Superquark_natura#Stagione_2020; last access: 4 May 2022.

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Author Contribution In this work, MB and RS designed and performed the experimental work; GC, LR, PS, JB, LMF, PN and GT performed specific experimental works in the framework of the '*Brunella*' *Project*; MT, JT and EK contributed to the formal organisation of the '*Brunella*' *Project* from the side of the Tuscan Superintendency and Banfi S.r.l. company; MB wrote the paper and provided the images; MB, RS, GC, LR, PS, JB, LMF, PN, GT, MT, JT and EK participated to the discussion and checked the manuscript and the images.

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Declarations

Conflict of Interest The authors declare no competing interests.

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