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Messor barbarus ants as soil bioturbators: Implications for granulometry, mineralogical composition and fossil remains extraction in Somosaguas site (Madrid basin, Spain)

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ABSTRACT

Few studies have inquired about the relationship between myrmecological activity and the granulometry and mineralogy of sediments of a palaeontological site. The objectives of this article are to determine the sedimentological or mineralogical distinctions produced by ants of the species *Messor barbarus* when excavating their nests and extracting grains and vertebrate fossil remains from the Miocene palaeontological site of Somosaguas (Madrid, Spain), to evaluate the degree of taphonomic influence this myrmecological activity has on the fossil remains, and to decide whether or not it can be used as a tool for palaeontological prospection. Results show that *Messor barbarus* does not alter fossil remains when examined under a 10× binocular magnifying glass. Ants preferentially extract from the ant nest grains of medium sizes (0.25–2 mm) compared to the non-ant-modified soils, and also extract a higher quantity of feldspars. These significant granulometric and mineralogical modifications should be considered when carrying out compositional, sedimentological or stratigraphical studies, since these can become biased and alter geological interpretations as provenance or palaeoclimatic signal. Grain size selection could be due to *Messor barbarus*' physical capacities or the use of clay particles as cementing elements in nests. Mineralogical distinction may be related to feldspars' embayments and pits filled with finer material (mainly smectites), making transportation and pheromone impregnation easier.

Results show that the ant mounds had increasing concentrations of fossil remains the nearer they were from the main excavation area, therefore the study of ant mounds in potentially fossiliferous zones can indeed be used as a new method of palaeontological prospection.

1. Introduction

Arthropods make up 90% of urban total fauna (Ruiz Heras et al., 2011; Carpintero and Reyes-López, 2014). Among them, ants stand out because of their number and biomass (Hölldobler and Wilson, 1990; Passera and Aaron, 2005). Many studies show how their activities can have a significant effect on human infrastructures (Robinson, 1996; Hill, 1997). Ant activity can bioturbate the surrounding soils, mostly due to colony formation, which is very diverse depending on the different ant species (Tschinkel, 2003). This bioturbation does not only affect soil stratigraphy and geochemistry, but can also increase water infiltration rates, runoff discharge and soil erosion (Lobry de Bruyn and Conacher, 1990; Cerdà and Jurgensen, 2008; among many others), and affect the voids formation and nutrient cycling regulation (Hole, 1981). Although foraging behaviours have been thoroughly studied throughout the genus *Messor* (Plowes et al., 2013), other behavioural mechanisms like different mineral compositions selection by this species must be further studied. Previous studies on bioturbation effects and the selective use of mineral grains by ants had shown mismatches between optical luminescence dating and artifact age (obtained by radiocarbon) in archaeological areas affected by ants' activities (*e.g.* Rink et al., 2013). Many studies have highlighted the relationship between the development of ant nests and variations in soil chemistry (Culver and Beattie, 1983; Wagner et al., 1997; Frouz et al., 2003;

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Wagner et al., 2004) or granulometry of extracted sediments (Wang et al., 1995; MacMahon et al., 2000; Nkem et al., 2000; Cammeraat et al., 2002; Dostál et al., 2005; Cosarinsky, 2006; Azcárate and Peco, 2007; Cosarinsky and Roces, 2007) but few studies have been carried out with a more detailed petrological and mineralogical focus when comparing the extracted sediment to the underlying unaltered sediment in fossiliferous areas.

Sand and sandstone petrography and sedimentology are useful tools to deduce geotectonic setting (Dickinson and Suczek, 1979), lithology and relief of a source area (Basu, 1985; Palomares and Arribas, 1993; Arribas and Tortosa, 2003) or palaeoclimate (Suttner and Dutta, 1986; Weltje, 1994; Fesharaki et al., 2015). Also, petrographic and clastometric analyses are important in soil characterization for environmental contamination, weathering, erosion, pedogenesis, agricultural studies or geoarchaeology (*e.g.* Courty, 1992; Le Pera and Sorriso-Valvo, 2000; Le Pera et al., 2001; Scarciglia et al., 2005; Zharikova, 2017; Goldberg and Aldeias, 2018). Burrowing and mounding activities of prairie dogs (Whicker and Detling, 1988), gophers (Sherrod and Seastedt, 2001), insects (Liu et al., 2007), worms (Needham et al., 2006) or benthic species (Rhoads and Boyer, 1982) represent local disturbances of soil and sediments characteristics (*e.g.* O'Brien, 1987). In addition, tunnels or chambers excavated belowground by ants can lead to intense bioturbation, involving mixing and accumulation of soils from different sources and horizons (Nkem et al., 2000; Halfen and Hasiotis, 2010; Rink et al., 2013) and changing soil textural properties (Paton et al., 1995; Folgarait, 1998). Therefore, areas heavily colonized by insects, for example by ants, could lead to misleading compositional or textural observations of the hosting soils and sediments if those modifications are not taken into account.

Moreover, since ancient times, the ability of ants as gold diggers has generated a great interest in scientists, as is evidenced in the Greek myths described by Herodotus (2007); but are some current works on termites and their termitaria (mounds constructed by them) which indicate the usefulness of social insects in mineral exploration (Petts et al., 2009). Nevertheless, ant mounds have not been systematically studied in order to be used as criteria for palaeontological prospection, even when fossil-collecting behaviour has been previously noticed in ants (Turnbull, 1959; Clark et al., 1967; Croft et al., 2004). Here lie the questions that motivated this study: (1) do *Messor barbarus* ants make any kind of distinction, compositional or granulometrical, at the time of sediment extraction while excavating their nests in a palaeontological area? (2) Are the changes generated by the myrmecological action significant when carrying out palaeoenvironmental and palaeoclimatic studies? (3) Do *Messor barbarus* ants alter taphonomically the fossil remains they extract from fossiliferous sites? and (4) Can ants' mound sediment study be used as a new tool for palaeontological prospection?

In this article we will determine to what extent *Messor barbarus* ants make a sedimentological or mineralogical distinction when extracting sedimentary particles at a fossiliferous site (Somosaguas fossil site) located northwest of the Madrid Basin (Spain). Sedimentary deposits of the Somosaguas palaeontological site have been chosen because they have been intensely studied (Fesharaki et al., 2012 and references therein; Domingo et al., 2017), and therefore the data obtained will be easy to compare (Fig. 1).

This area presents a high abundance of *Messor barbarus* Linnaeus 1767 (Hymenoptera: Formicidae) nests. *Messor barbarus* is a highly polymorphic grain-collector ant species (Heredia and Detrain, 2000) common on Mediterranean grasslands of Southern Europe and Northern Africa (Detrain et al., 2000). They build complicated nests composed by a big network of galleries and interconnected chambers that can reach 5 m in depth and in those cases where it does not, the nest can spread out up as much as 25 m^2 over the surface (Bulot et al., 2014). The nest is excavated and maintained mainly by worker ants that use their mandibles, with a gap range between 0.80 and 2.80 mm (Oliveras et al., 2005), to transport mineral particles and soil pellets outside the nest. The maximum size and weight of materials that a *M. barbarus* worker can transport are still poorly known, but they have been documented carrying soil pellets up to 11 mm (Shipman and Walker, 1980; Durán, 2011) and 50 mg (Detrain and Pasteels, 2000), but it can be assumed that the size of soil particles transported by ants depends on the size of their mandibles (Dostál et al., 2005). As a granivore species, *M. barbarus* prefers grasslands and high temperature locations for their nest in order to facilitate soil water evaporation and seed preservation (Bernard, 1958; Rodríguez, 1982; Rodríguez and Fernández Haeger, 1983). Although there are up to ten recognized species of *Messor* in the Iberian Peninsula, it is highly unusual to find two or more different species in the same area (Espadaler and Suñer, 1995) due to the limiting factor of the territory which can influence nest size and new nest formation in those areas where 15% of the land is covered by nests (Nielsen, 1986). Besides *Messor barbarus* it is possible to find two other ant species in the immediate Somosaguas fossil sites surroundings: *Camponotus cruentatus* Latreille, 1802 and *Aphaenogaster senilis* Mayr, 1853. *Camponotus cruentatus* is a common species throughout the Mediterranean region where it excavates its nests in dry soils. Their colonies are made up of a few thousand workers which inhabit monodomous nests that rarely exceed 65 cm deep and have a surface of 2–4 m^2 (Boulay et al., 2007). *Aphaenogaster senilis* is an omnivorous species which feeds on a wide range of prey and, to a lesser extent, vegetable remains (Barroso Rodríguez, 2013), distributed all along the Mediterranean basin (Galarza et al., 2012). They form small colonies of 200–1500 workers (Barroso Rodríguez, 2013). It is a strongly migratory species. After they migrate, former ant nest retain their whole structure of galleries and chambers which allows reutilization by the same or another colony which reduces the need of excavating a new nest and thus also reduces its impact on the underlying materials (Galarza et al., 2012). Due to its textural characteristics, with poorly and irregularly cemented sediments (Fesharaki, 2016), the surroundings of the Somosaguas palaeontological site make a favorable area for these organisms to stablish their nests.

As already mentioned ants carry particles to surface mounds during nest construction and continually improve and modify these constructions. Previous literature about these nesting activities has shown the preference of ants to use certain particle sizes for building. Wang et al. (1995) described a preferential selection of grains by *Lasius neoniger* ants when building their galleries, using the coarse grains infilled by the finer particles as cementing materials, and more recent observations on *Temnothorax albipennis* indicate that when selecting material for wall-building they choose large sand grains as well as smaller ones to construct mixed grain-size walls that are more compact and strong (Aleksiev et al., 2007). Some authors (Wang et al., 1995; Cosarinsky, 2006; Cosarinsky and Roces, 2007) have described a preferential selection of grains by ants when building their galleries, using finer particles as cementing materials. *Atta vollenweideri* ants when have the possibility to use sands and also clays they build mixed structures with sand walls infilled by clay aggregates or pellets (Cosarinsky and Roces, 2007). Similar behaviour has been described for other ant species like *Camponotus punctulatus* or *Solenopsis* sp. (Cosarinsky, 2006; Gorosito et al., 2006). Paton et al. (1995) indicate that mounds constructed by *Aphaenogaster* ants are usually depleted in gravel, coarse sand (grains larger than 2.5 mm are absent) and clay when compared with the surrounding soils (Richards, 2009). *Iridomyrmex purpureus* build their galleries using a mixture of silt and saliva (Ettershank, 1968) while *Pogonomyrmex occidentalis* pack soil materials during reinforcement of nets' walls (Halfen and Hasiotis, 2010). Drager et al. (2016) documented silt enrichment in surface mounds of the species *Formica subsericea*. Many other authors have observed an increased percentage of silts and/or clays in the mounds built by different ant species compared to the surrounding soil (MacMahon et al., 2000; Cammeraat et al., 2002; Whitford, 2002; Dostál et al., 2005; Azcárate and Peco, 2007), whereas others have observed that sand fractions are preferentially deposited in the mounds (*e.g.* Nkem et al., 2000). Possibly many species of ants are able to select different types of material (*e.g.* clays or coarse