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The Significance of Subtlety: Contrasting Lithic Raw Materials Procurement and Use Patterns at the Oldowan Sites of Barranco León and Fuente Nueva 3 (Orce, Andalusia, Spain)

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Situated in southern Spain's Guadix-Baza basin, Barranco León and Fuente Nueva 3 (Orce, Andalusia, Spain) are two of the most important western European Oldowan archeological sites. After 30 years of quasi-uninterrupted excavations, these two occurrences have yielded exceptional lithic and faunal records in precisely dated stratigraphic situations, providing a wealth of information about the oldest presence of hominins outside of Africa (1.4 and 1.3 Ma, respectively). Recently, excavations and multidisciplinary research have allowed to discern new patterns of lithic raw material procurement and use patterns practiced by the Orce hominins that enable us to clearly distinguish different behavioral schemes between these two sites; in spite of their spatial proximity. This paper explores new data from the lithic collections in relation to hominin technical and economic behavior, highlighting subtle but significant differences in their exploitation of local limestone and flint clasts more than a million years ago. During this period of the late Early Pleistocene, these sites were situated on the shores of an ancient saline lake and fresh water sources were available. This favorable environmental situation, while attractive to the hominins, also supported life for an abundance of large mammals, including competitive large carnivores, underlining questions of expedience as an influence on techno-morphology in these early stone toolkits. This paper analyzes these themes, highlighting updated information from these and other key European late Early Pleistocene sites.

Keywords: Orce, lithic raw materials, technology, stone tools, hominin behavior, Oldowan

1 INTRODUCTION

The Oldowan sites of Barranco León (BL) and Fuente Nueva 3 (FN3) are located in the Guadix-Baza depression near the town of Orce (Spain). Placed at an altitude of ~1,000 m. a.s.l. and only 4 Km apart from one other, these unique Oldowan occurrences have been the object of excavations and archeological research since the early 1990s. While in the past these sites, dated respectively to 1.4 and 1.2 Ma, have commonly been confounded into the single referent 'Orce', they constitute distinct depositional contexts composed of multiple layers containing archeo-paleontological materials. It is precisely these subtle but significant differences in environmental conditions and site formation processes that we present here as revelatory of behavioral shifts in lithic raw material's sourcing and use by their hominin dwellers. This paper focuses on intra and inter-site specificities to compare behavioral patterns relative to lithic raw material's gathering, exploitation, use and discard. In spite of the paucity of information from the European human fossil record dating to this period, this special focus unites all of the data obtained up to now from both lithic assemblages to reveal information about the social and cognitive practices of the first human populations present in Europe. As is in other Oldowan lithic assemblages, the hominins present at Orce well-over a million years ago exploited local raw materials collected from around the sites and even within the depositional sequences themselves (Barsky et al., 2015a; Titton et al., 2021). At BL and FN3, limestone cobbles and blocks, as well as flint nodules, were picked up, transported and used by the hominins, generally from detritus erodes from the Jurassic formations around the sites. In spite of this local raw material procurement strategy, interesting patterns of exploitation and use are identifiable as factors that contribute significantly to our understanding of selective behaviors and preferences in raw material uses that differ in subtle but significant ways between the two archeological occurrences.

To better understand hominin behavioral aspects in terms of lithic raw materials, we begin by providing a synthesis of the geo-archeological contexts of BL and FN3, highlighting new information about their specific climatic, environmental and depositional features, before more closely examining their role as potential conditioning factors. This in turn raises interesting issues about the role of technology in overcoming natural constraints and thus becomes highly revelatory of hominin cognitive processes in dealing with the specific landscape circumstances that may have been dictating these behaviors. In the case of BL and FN3, this type of analysis takes on special significance because it allows to build up a discussion about how technological conducts played a role as a favoring aspect, finally enabling early hominin groups to successfully and durably implant themselves in western Europe. In recent years, our research has deeply explored the dichotomous use patterns displayed by the Orce hominins in their exploitation of limestone and flint, with the former showing especially high morpho-techno-variability (Carbonell et al., 2009), in particular relating to an unprecedented range of percussive activities (Barsky et al., 2015b; Barsky et al., 2018; Titton et al., 2018). The limestone assemblages contain flakes, cores, and chopper and percussive-type tools, while the flint reflects only the production of small-sized flakes. Despite seeming stability, we find remarkable differences in the operative permanency between the sites. The BL and FN3 toolkits now comprise a total of 3,925 flint and limestone pieces (BL = 2,434 pieces; excavations 1995–2018 and FN3 = 1,491 pieces, excavations 1995–2017) (**Table 1**), currently making them one of the best references for understanding the specificities of the 'European Oldowan' (Titton et al., 2020). In addition to the lithics, both sites have yielded rich assemblages of mega, large and medium to small-sized mammals (faunal remains: BL = 34,045 and FN3 = 22,623, after new inventory (Junta de Andalusia, Museum of Ethnography and Archeology of Granada), as well as rich collections of micro fauna that, supported by radiometric dating, contribute to our growing knowledge about the biochronology and climatic/environmental settings (detailed below with references). As a final step, we apply here the behavioral templates provided by the Orce contexts to perform a comparative analysis synthesizing what is known about raw material exploitation in other European Oldowan sites.

2 THE BARRANCO LEÓN AND FUENTE NUEVA 3 SITES: ENVIRONMENTS AND CONTEXTS

2.1 Geographical Context and Discoveries of the Barranco León and FN3 Sites

The Guadix-Baza basin (GBB) spans a large surface area of the southeastern sector of the Iberian Peninsula (4,500 km^2) at the contact between the Internal Zones (mainly built up of Paleozoic basement rocks) and the External Zones (mainly built up of Mesozoic carbonate cover rocks, **Figure 1**). This intramontane basin is well-known to geologists who have explored the different layers of its thick and continuous depositional sequences since the 1970s (Vera, 1970; Vera et al., 1985; Soria et al., 1987; Hüsing et al., 2010; Oms et al., 1998; Oms et al., 2000a; Oms et al., 2016). The GBB encloses a unique continental Plio-Pleistocene and Holocene record from the Late Turolian and Middle to Late Pleistocene (Soria et al., 1998) that is characterized by two main depositional contexts: 1) the western Guadix sector of the basin, characterized fluvial sedimentation and 2) the mostly lacustrine eastern Baza sector, which hosts the Orce sites of BL and FN3 (Oms et al., 1998). The salient geographical feature of the Baza sub-basin was the prolonged existence (~5 million years) of a saline lake, bounded to the north by the External Zone (Sierras de Cazorla, Maria and Umbría) and to the south by the by the Sierra Nevada. The extension and morphology of the lake varied through time with the vicissitudes of changing climatic and tectonic contexts that also affected freshwater inputs to the system, originating both from the surrounding mountain ranges and from underground perennial sources; some of which are still active today (Oms et al., 2016) (**Figure 1D**). The Baza Formation is subdivided into three members: the Lower Member is calcareous (composed of shallow lacustrine

TABLE 1 | Distribution of the different kinds of tools composing the lithic assemblages of the Barranco León (1995–2018) and Fuente Nueva 3 (1995–2017) sites in accordance to the two main raw materials. Note in Barranco León that there are 15 items that have been preliminarily attributed with different raw material determinations that have yet to be explored in detail: 6 non-modified clasts, 1 knapped/shaped item, 3 flakes, fragmented flakes and flake fragments and 5 debris. In Fuente Nueva 3 there are 17 items that have been preliminarily attributed with a different raw material: 2 non-modified clasts, 1 knapped/shaped item; 10 flakes, fragmented flakes and flake fragments and 5 debris.

Tool Category	Barranco León		Fuente Nueva 3	
	N	%	N	%
Limestone non-modified clast	231 +51 hammerstones	34.6	78 +48 hammerstones	15.2
Limestone knapped/shaped (macro)	87	10.7	99	12.0
Limestone whole and broken flakes	130	15.9	253	30.6
Limestone debris	317	38.8	349	42.2
Total limestone	**816**	**100%**	**827**	**100%**
Flint non-modified (macro)	1+ 57 small pebbles	3.6	1	0.2
Flint knapped	55	3.4	30	4.5
Flint whole and broken flakes	729	45.0	524	78.9
Flint debris	776	48.0	109	16.4
Total flint	**1,618**	**100%**	**664**	**100%**
Total assemblage	**2,434**	**Limestone= 33,5% Flint= 66,5%**	**1,491**	**Limestone= 55,5% Flint= 44,5%**

Bold letters in table indicate totals.

limestone); the Middle Member is composed of detrital materials including reddish alluvial clays, sandstones, marshy clays and limestone and the Upper Member (comprising the two Oldowan sites) is an accumulation of lacustrine limestones, calcareous silts, dark clays, sands and locally formed gypsum (Vera et al., 1985; Soria et al., 1987; Oms et al., 2000a; Oms et al., 2000b; Oms et al., 2011).

The fluctuations of the lake's extension and depth generated marginal lacustrine and palustrine settings that permitted the accumulation and preservation BL and FN3 sites (**Figure 2**). Basin infill lead to the drying of the lake in the Middle Pleistocene and towards the end of the Pleistocene, it became part of the Guadalquivir River catchment. Thus, the basin started to be an exoreic system that at some places is leaving sedimentary successions of over 100 m encompassing hundreds of thousands of years. Erosive forces are opening up huge ravines and are lending the region its almost 'lunar' aspect. The enormous sedimentary sections thus exposed offer particularly advantageous circumstances for geo-archeological investigations, while also providing ideal conditions for the digging-out of cave homes for troglodyte dwellings (*casas cuevas*) linked to the rebellion and expulsion of the "moriscos" (Hispanic-Arab population converted to Christianism) in the XVI century (Asenjo Sedano, 1972; Urdiales Viedma, 2003). In 1976, surveys undertaken in the Baza sector of the GBB led to the discovery of Venta Micena; a vast paleontological site devoid of any human presence that predates BL and FN3 by some 200 Ka (*ca*. 1.6 Ma, Duval et al., 2011; Agustí et al., 2010a; Agustí et al., 2015a). The VM4 site, site has recently been shown to consist of two distinct layers corresponding to separate depositional events (Luzón et al., 2021). The site was formed by freshwater inputs above the water table of the nearby saline Baza lake (Granados et al., 2021). Recent publications have shown that climate could have been a key limiting factor for the arrival/installation of hominins some 200 thousand years later (at BL and FN3), following the establishment of a somewhat more clement climatic situation in this area (Blain et al., 2011, 2016; Sánchez-Bandera et al., 2020; Saarinen et al., 2021). In 1983, surveying in the region of Orce led to the discovery of BL, which was initially recognized as a paleontological site (Vera et al., 1985), until 1994, when the first lithics were found (Gibert et al., 1992; Gibert et al., 1998). In 1991, the first flint tools were discovered at the nearby site of FN3 (only 4 Km away from BL) by a local inhabitant and, in 1992, more archeological materials were unearthed during the installation of a telephone pole, leading to the undertaking of the first test excavations (Tixier et al., 1995; Turq et al., 1996; Martínez-Navarro et al., 1997; Gibert et al., 1998).

2.2 Stratigraphy and Dating of the Barranco León and FN3 Sites

Over years of excavations and research, the BL and FN3 sites have been analyzed using a multidisciplinary approach that has enabled to chrono-stratigraphically categorize both depositional and occupational contexts. Indeed, the full lateral extension of these open-air Oldowan sites remains unknown and their discovery has been contingent to findings made fortuitously, basically during surveys in the region. Doubtlessly, these occurrences constitute auspicious finds, where a hominin presence has been registered in water-rich environments favorable to all forms of life. Hominins were present around the Baza lake area, moving through the landscape amongst the numerous other mammal species occupying the zone and taking advantage of favorable and life-promoting conditions. Indeed, apart from the hominin presence that is clearly registered (as stated above) by the very numerous Oldowan stone tools (Toro-Moyano et al., 2010,

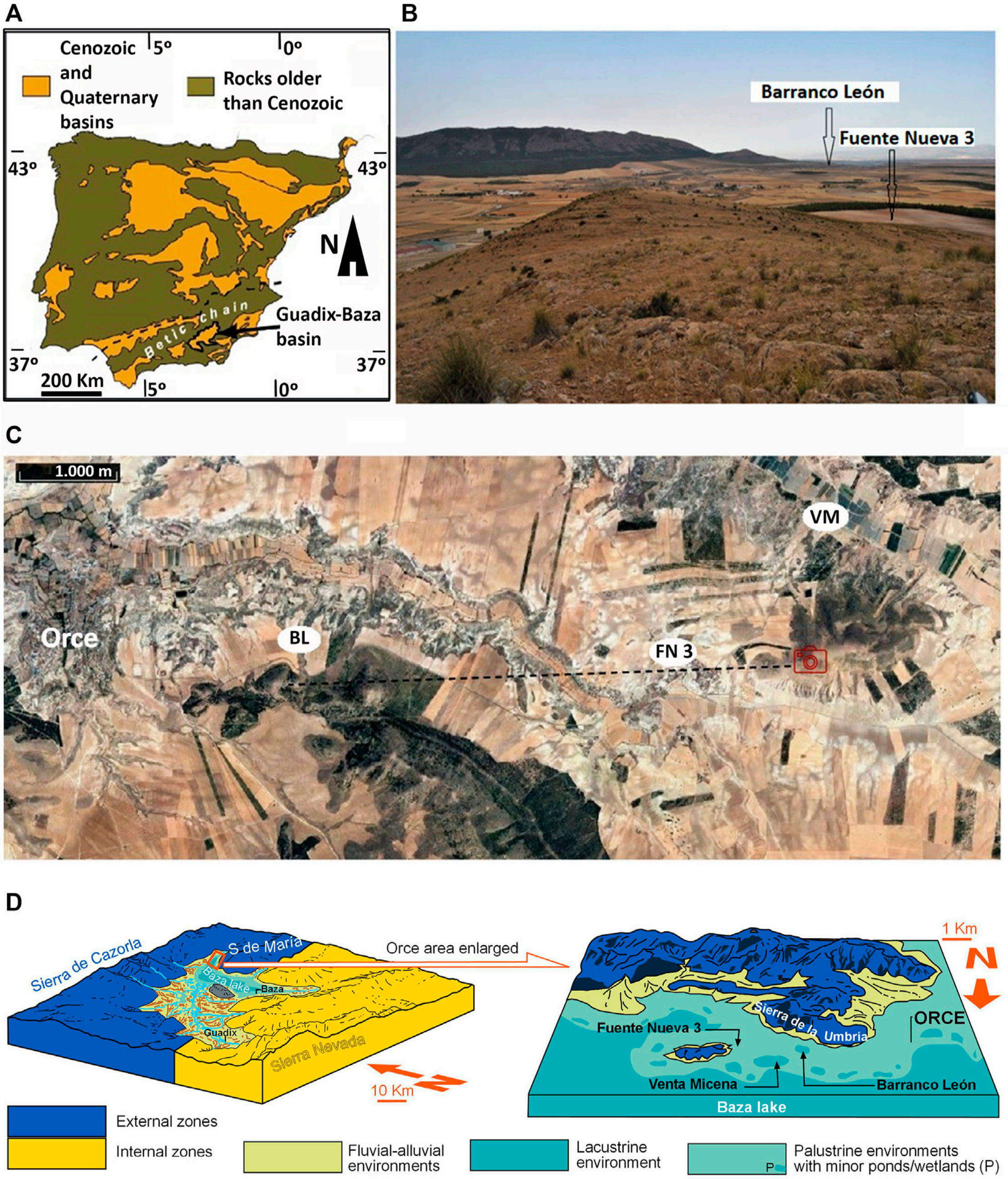

FIGURE 1 | (A) Location of the Guadix-Baza Basin in Spain (image inset) **(B)** Location of Barranco León and Fuente Nueva 3 with respect to the slope of the Sierra Umbría (Photo: S. Titton) **(C)** Satellite view showing the location of the BL and FN 3 in relation to the village of Orce (Image from Google Earth, Titton, 2021). Site locations and photograph **(B)** Capture situation facing BL from the promontory of the Cañada del Campo near FN 3 **(D)** Geological block diagrams illustrating the context and positioning of the Venta Micena paleontological site and the Oldowan sites of BL and FN 3 in relation to the fluctuating shoreline of the Baza paleo lake (adapted after Oms et al., 2016).

Moyano et al., 2011); both of the sites have yielded a wide range of herbivores and carnivores with little differences observed in species' relative representation between the two sites (e.g., Martínez-Navarro et al., 2010; Ros-Montoya et al., 2021; Saarinen et al., 2021). Meanwhile, biochronology and climatic features for each site have been refined thanks to numerous and ongoing studies of the relatively abundant micro-vertebrate assemblages that include micro-mammals and herpetofauna (Blain, 2005; Blain, 2009; Agustí et al., 2010a; Agustí et al., 2010b; Bailon, 2010; Blain and Bailon, 2010; Furió, 2010; Blain et al., 2011; Lozano-Fernández et al., 2015; Agustí et al., 2015a; Blain et al., 2016; Sánchez-Bandera et al., 2020). The dating of the sites was originally achieved thanks to a combination of magnetostratigraphy and

FIGURE 2 | General views of the Oldowan sites of Barranco León and Fuente Nueva 3 sites: 1) View of the Barranco León site on the edge of the ravine (Photo: Chmiel F.L.); 2) View of excavations at the Barranco León site in 2020 (Photo: J. Cámara); 3) View of the Fuente Nueva 3 site (Photo D. Barsky); View of the *Mammuthus meridionalis* tusks *in situ* in level 5 of the Fuente Nueva 3 site (Photo: J. Cámara).

biochronology. Both sites show reverse polarity and are attributed to the Matuyama Chron, preceding the Jaramillo normal subchron (>1.07–0.99 Ma) (Oms et al., 2000a; Oms et al., 2000b; Oms et al., 2003; Oms et al., 2011). The micro-mammal assemblages of both sites place them in the regional *Allophaiomys* aff. *lavocati* biozone (Agustí et al., 2010a; Agustí et al., 2010b; Agustí et al., 2015b). A younger age for the FN3 site was attributed after the identification of evolutionary differences between the *M. savini* populations from BL and FN3 (Lozano-Fernández et al., 2015). Additional U-series and ESR dating has been carried out using quartz grains and dental materials (BL: levels D1 and D2 weighted average ESR age of 1.43 ± 0.38 Ma and FN3: age range from 1.67 to 1.34 Ma, Toro-Moyano et al., 2013; Duval, 2008, Duval et al., 2011; Duval et al., 2012a; Duval et al., 2012b), as well as cosmogenic nuclide age evaluation (burial age 1.50 ± 0.31 Ma at FN3, Álvarez et al., 2015). The biochronology supports the numerical data and the combined methodologies constrain the magnetostratigraphic readings confirming a pre-Jaramillo age for both sites and allowing to propose an age close to 1.4 Ma for BL and to 1.2 Ma for FN3.

While a water-rich environment is clearly defined for both occurrences (Anadón et al., 2003; Oms et al., 2011; García-Aguilar et al., 2014), further refinement of the climates and environments reigning during the different periods represented in each level of the BL and FN3 sites have been obtained in recent years. By combining stratigraphy, geochronology and biostratigraphy, information can be obtained about inter and intra-site variability, allowing to draw new inferences about hominin behavior and survival strategies at the sites. For example, paleoenvironmental reconstructions made by examining successive assemblages of fossil amphibians and reptiles excavated from the different levels of each sequence indicate progressive aridity through time at BL (from level D1 to level E), whereas in FN3 aridity characterizes only level 5 (Sánchez-Bandera et al., 2020). These results demonstrate flexibility on behalf of the hominins present at the sites in the face of the late Early Pleistocene climatic cyclicity (interglacial and glacial), suggesting they were able to cope with changing environmental conditions. This information has recently been buttressed by a study of amphibian body size (Martínez-Monzón

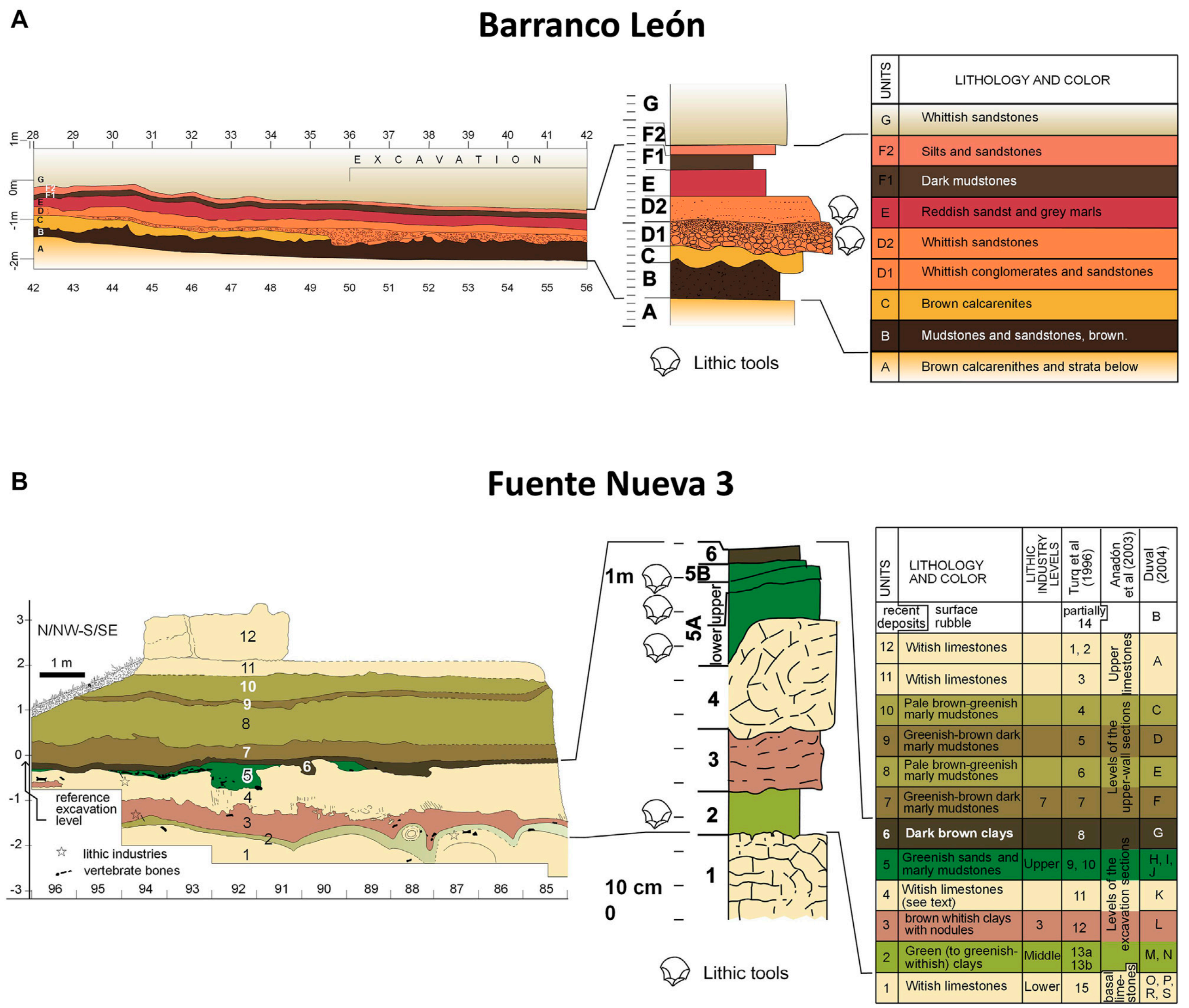

FIGURE 3 | (A) Stratigraphic section and main sedimentological features of the Barranco León site. **(B)** Stratigraphic section and main sedimentological features of the Fuente Nueva 3 site (Figures re-drawn by O. Oms after Oms et al., 2011 and Sánchez-Bandera et al., 2020).

et al., 2022), showing that female frogs became significantly smaller during the interglacial stages, when species' richness increased, while they underwent size increase during the more arid glacial periods characterized by fewer resources. Main explanations proposed to justify this pattern are the "water-availability hypothesis" and a trade-off between somatic growth and reproductive opportunities for females (Martínez-Monzón et al., 2022).

Before moving on to discuss the cultural aspects in relation to raw material procurement and use as observed from the BL and FN3 lithic assemblages, some additional observations are worthwhile noting as they allow further refinements in intra and inter-site climatic and vegetation settings that will be important when considering hominin behavior. Recently published data about the dental mesowear signals calculated from large mammals (e.g., elephant, hippo, horse) and indicative of their browsing or grazing diets (with a more abrasive grass-rich diet showing flatter wear angles), shows that browsers or mixed feeders dominated at both BL and FN3, while mainly grazers were present at VM (Saarinen et al., 2021). This evidence underlines the harsher climatic conditions dominating during the formation of the VM paleontological site, suggesting that the arrival of hominins in western Europe occurred during a more clement period of climatic conditions at the BL and FN3 sites. In this study, mean annual precipitation, temperature of coldest month and net primary productivity were estimated for the GBB sites based on dental trait distribution in the large herbivorous mammals, and compared with African Pleistocene hominin sites and values for modem biomes. Moreover, the predominance of browsing large mammals in FN3 and BL indicate an environment where grasses were scarce. This significantly changes the commonly held 'savannastan' hypothesis (*sensu* Dennell and Roebroeks 2005), whereby it was assumed that the first hominins moved into western Europe because of savannah-type conditions presumably analogous to those of their 'african homeland'. Main results show that climate and vegetation in VM were roughly similar to a Mediterranean forested steppe, while evergreen Mediterranean forests and woodlands or shrub lands dominated during the hominin occupations of BL and FN3. Similarly, carbon and oxygen stable isotopes analyses carried out using tooth enamel from large herbivore dental remains excavated from VM, BL and FN3 (Bocherens et al., 2020), suggests more significant seasonal variations in aridity and vegetation at VM, confirming a harsher climate setting there in comparison with the BL and FN3 hominin sites. All of these multidisciplinary analyses contribute to changing the picture of Oldowan hominin ecological flexibility in southwestern Europe 1.4 to 1.2 Ma, while also highlighting important differences between the Oldowan sites; with BL being globally more humid with more diverse vegetation than FN3.

2.2.1 Barranco León Stratigraphic Sequence

The BL site is situated within a 70 m thick section of alluvial and lacustrine deposits exposed after the formation of the ravine (Barranco). Divided into 10 levels (Anadón et al., 2003), the site's stratigraphic sequence (**Figure 3A**) shows a thickness of some 2 m and is composed of a series of different strata of carbonated clays and siltstones, limestone, sand and conglomerates that include some sterile levels with micro and macro paleontological remains. The D level (BL-D previously BL-5) that has yielded the bulk of the lithics and a broad spectrum of faunal remains, including a dental fragment attributed to *Homo* sp. (Toro-Moyano et al., 2013), has been divided into two different levels (levels D1 and D2, Anadón et al., 2003; Oms et al., 2011). As indicated above, an age close to 1.4 Ma has been determined for the anthropic occupation of level D1 (Toro-Moyano et al., 2013). Levels D1 (65 cm thick) and D2 (20 cm thick) correspond to two distinct phases of deposition (Oms et al., 2011; Titton et al., 2021), accounting for high taphonomic variability characterizing the lithic and paleontological finds. Level D1 (deposited on the sterile archeo-stratigraphic unit C composed of calcarenite) was formed during a phase of high energy water transport and is characterized by an accumulation of (limestone) gravels, pebbles, cobbles, as well as some large-sized slabs (Oms et al., 2011; Titton et al., 2021). Contrastingly, level D2 is a compact deposit of greyish bio-plastic sands accumulated by *in situ* sedimentation. Level D2 was subsequently overlain by the dark green-colored clastic mudstone deposits of level E, containing only sparse archeological evidence.

2.2.2 Fuente Nueva 3 Stratigraphic Sequence

The FN3 site contains a stratigraphic section some 5 m thick with a total of 12 distinct levels of sedimentation, two of which (level 2 and level 5) have yielded most of the archeological and paleontological finds (with only sparse remains reported from levels 1 and 3). The sequence (**Figure 3B**.) is mainly composed of limestones, mudstones and sandstones (Oms et al., 2011). The age of the succession has been measured using magnetostratigraphy (within the negative Matuyama chron) and radiometric dating refined by biochronology (Oms et al., 2000b; Duval et al., 2012a; Duval et al., 2012b; Álvarez et al., 2015; Lozano-Fernàndez et al., 2015) and is presently fixed at close to 1.2 Ma. Situated on the Baza lake margin, the FN3 lacustrine-palustrine sequence corresponds to gradual sedimentation within the late Early Pleistocene successive climatic events, wherein the anthropic layer 5 accumulated in a colder, glacial period, relative to the warmer and more humid conditions of level 2 (Sánchez-Bandera et al., 2020). The two anthropic layers are separated by mainly sterile sediments of level 3 (brown whitish clays with carbonated nodules) and sterile level 4 (whitish limestones). Recent excavations have allowed to divide level 5 (composed of green-colored sands and marly mudstones) into at least two sublevels (superior and inferior), based on lateral variations of facies and taphonomic alterations. Sedimentological features of level 5A present lateral variation and are studied micromorphologically, leading to its sub-division in correspondence with climato-contextual events (Jiménez-Arenas et al., 2021): level 5B (composed mainly of dark-brown clays), yields fragmented and small-sized bone fragments and sparse lithics and represents a relatively humid period of lake expansion. Meanwhile, level 5A (superior and inferior, composed respectively of cemented and loosely compacted green sands and lutite) is related to a colder and dryer climatic episode (Oms et al., 2011; Sánchez-Bandera et al., 2020). The entire sequence shows sloping towards the southwest and has been quite deeply affected by different taphonomic forces, including high salt content and water flow, as well as gravitational damages that have caused some faulting and otherwise affected the integrity of the sections. As the name of the site suggests, the landscapes of FN3 (past and present) have been affected by the presence of water that likely attracted the hominins and other animals to the area for thousands of years.

3 MATERIALS AND METHODS

3.1 Excavations

Fieldwork at both sites has continued nearly uninterrupted since their discovery in the 1990s. The excavations in extension have followed the three-dimensional Cartesian 1 m^2 grid projection method commonly used to excavate Paleolithic sites (Laplace, 1971). Each square of the grid is named following the correspondence for the *X* and *Y* axes (respectively, letters and numbers). Excavations follow the sedimentary levels, attributing the archeo-paleontological materials to the identified layers to gain global vision of each sedimentary event. Spatial relationships are recorded to discern the original paleotopography of each level. While different research teams have worked at the sites over the years, excavations since 2010 have followed uniform protocols, facilitating the exploitation of homogenized databases to exploit

TABLE 2 | Types of rocks identified macroscopically in the lithic series of Barranco León and Fuente Nueva 3 (after Grégoire, 2009; Toro-Moyano et al., 2010).

Code BL	Rock Type	Color	Patina	Cortex	Block Morphology
Barranco LEÓN					
CBL 1	Siliceous limestone	Beige/green to orange			Large round cobble
CBL 2	Marly limestone	White-beige			Large round cobble
CBL 3	Oolithic limestone	White-beige		Thin, globular	Nodules
SBL 1	Flint	Green	Rare, yellow	Thin, white carbonated	Small nodules
SBL 2	Flint	Grey	Rare, white	Thin, white, porous	Large nodules
SBL 3	Flint	Beige-grey	Grey, light	?	?
SBL 4	Flint	Grey ?	Total white	?	?
FUENTE NUEVA 3					
Code FN 3	**Rock type**	**Color**	**Patina**	**Cortex**	**Block morphology**
CFN 1	Marly limestone	Beige-grey		?	Rounded nodules
CFN 2	Siliceous limestone	Beige-orange		?	Rounded nodules
CFN 3	Siliceous limestone	Grey-beige		?	Cobble
CFN 4	Sandy limestone	White		Thin, white	Cobble
CFN 5	Fossiliferous limestone	Black		Thin with fossils	Small nodules
QZFN 1	Quartzite	Grey		?	?
SFN 1	Flint	Beige-grey ?	White to yellowish	Thin, light, siliceous	Rounded
SFN 2	Flint	Grey with white fossils	White	?	?
SFN 3	Flint	Grey	Yellowish	Carbonated or siliceous, very thin	Small rounded nodules
SFN 4	Flint	Green to orange		?	?
SFN 5	Flint	Brownish		?	?
SFN 6	Flint	Grey		?	?

different kinds of data obtained from the sites. Non-identifiable fossils >2 cm long are coordinated, as are all lithic items and identifiable faunal remains; regardless of their size. Every coordinated item is assigned to an individual record with its spatial information and, if possible, preliminary classification data. A computerized register system is used to record basic field data. Sediment collected from the excavations is washed and sieved in accordance to its provenance to recuperate smaller-sized items (i.e., micro faunal remains). All of the archeo-paleontological materials are prepared in the field laboratory (cleaning, labeling, graphic documentation and restoration tasks) and distributed for study by the specialists.

3.2 Surveying

Surveying for lithic raw materials in the vicinity of the archeological sites of BL and FN 3 sites contributes to our knowledge about hominin lithic procurement patterns and environmental contexts (availability, format and quality of raw materials accessible to hominins during the occupation of the sites). In addition, it contributes to developing a more thorough understanding about how the availability of rocks apt for knapping and pounding played a role in the occupation of these sites. Over the years, specialists have pinpointed numerous flint outcrops and their detrital areas, also defining qualitative features (Toro-Moyano et al., 2007; Toro-Moyano et al., 2010, and references). During recent surveys we verified previously documented information; geo-localized significant findings; registered changes in environmental configurations, performed photographic documentation and collected lithic samples for experimental and didactic archeology (Barsky et al., 2018; Titton et al., 2018, Titton et al., 2020; Yravedra et al., 2021). Experimental knapping/use contributes to knowledge about the mechanical qualities of the different kinds of stones found in the archeological samples. As first links in a lithic operative chain, the choices made by hominins in selecting their raw materials involved noteworthy decision-making processes (i.e. evaluation of a rock's adequacy for the task at hand: size, shape, quality, fracture mechanics). A central pillar of research on the archeological stone tools, surveying reveals important information about: 1) Raw materials (variability and availability, formal attributes, qualitative diversity); 2) Hominin behavior and selective processes (mobility and lithic transport, technological strategies applied to different rock types in accordance to: clast size, shape, quality and mechanical features and relating tool types to raw materials in accordance to these criterion) and 3) Archeological site contexts (familiarity with the geological context is essential to assess archeological situations and compare contextual features).

3.3 Petrography

Up to 2010, petrographic analysis and microscopic characterization focused on the siliceous sedimentary materials (Toro-Moyano et al., 2010) from the lithic collections (excavations up to 2004). Based on macro-characteristics, a total of 4 groups of flint and 3 groups of limestone (silicified, marly and oolithic limestone) were recognized for BL and 6 groups of flint and 5 groups of limestone for FN 3 (**Table 2**).

Thin-section petrographic research was carried out for each of the two series, allowing to group together some of these types that were found to be identical from the micro-facies point of view. In parallel, characterizing the different facies observed in the lithic assemblages, prospecting and sampling in the vicinity of the sites have made it possible to locate the main outcrops in the Jurassic formations (Baena Pérez et al., 1979) and to identify areas of secondary deposits of these same materials, while providing accurate mapping of primary outcrops and secondary deposits (Grégoire, 2009; Toro-Moyano et al., 2007, 2010). A first regional lithological repository of the Sierras of Orce and Maria has been established with the dual objective of characterizing the flints of this area and preserving reference samples for future studies (our lithic referential will be made available to researchers at the *Centro de Interpretación Primeros Pobladores de Europa 'Josep Gibert'* in Orce). Microfaciological characterization of the types of flint recognized in the lithic series and of the samples taken from the various outcrops, allow to compare between facies and thus to attribute one or more potential sources to each type of flint. Places of collection of flint blocks by hominins can thus be proposed. This study reveals that the most frequent flints in the two series come from the highly developed Jurassic Dogger formations, particularly in the Sierra de la Umbria and Cerro Gordo sectors, less than 5 Km from the sites. The SBL 2, 3 and 4 and SFN 1, 2 and 3 facies come from Bajocian limestone formations and the other types have been identified in the Barthonian and more rarely, in the Malm.

The established lithological cartography is then used as a reference to calculate the minimum and maximum supply distances for the exploitation of each flint type. A geochemical characterization was also attempted on the flints. It revealed the frequent presence of carbonate inclusions (CaCO3), in particular in the flints from BL. No other element has been identified at this stage through surface analyzes using the EDX microprobe coupled with SEM observations. During this initial characterization research on the rocks from both assemblages, all the facies (flint and limestone) identified in the two lithic series were located at one or more outcrop points (except for the quartzite present in small quantities in the lithic series of FN 3). More recently, additional macroscopic observations were applied to facilitate the search for refitting or conjoining flint lithics, as well as to evaluate possible hominin selective processes concerning the limestone raw materials (Titton et al., 2018; Titton et al., 2021). Accordingly, a subdivision of the two dominant rock types (flint and limestone) was carried out, determining sub-groups *Raw Material Units* (RMUs) based on dominant macroscopic petrographic characteristics (color, texture, granulometry, cortex, presence/absence of crystallization planes, trace elements, fracture planes and inclusions; Roebroeks, 1988; Vaquero, 2008; Machado et al., 2013). Limestone cobbles with no anthropic traces from the depositional context of the BL site were included in the analysis. This method was applied to compliment previously made observations (Toro-Moyano et al., 2010) for the lithic collections up to 2018, in the framework of a PhD thesis concerning the BL assemblage (Titton, 2021). Thus, at BL, a total of 9 flint and 5 limestone RMUs were distinguished and correlated with previous determinations from Toro-Moyano et al. (2010) (Titton et al., 2018; Titton et al., 2021).

3.4 Lithic Studies

The lithic toolkits from BL and FN3 are studied using a combination of classical and innovative methodologies (Barsky et al., 2015a; Titton et al., 2020; Titton, 2021): morpho-technological analyses; description of lithic taphonomic characteristics (alteration and patina); experimental archeology; artifact's spatial distribution; investigation for refitting and conjoining lithic sets. Each lithic is examined on the basis of the criteria established by the methodology of analysis of tool categorizations (Bordes, 1961; Leakey, 1971; Clark and Kleindienst, 1974; Chavaillon and Chavaillon, 1976; Isaac, 1977; Chavaillon, 1979) and the "position" of each piece in the operational chains is determined (Carbonell et al., 1983; Carbonell et al., 1992; Geneste, 2010; Soressi and Geneste, 2011). Adhering to the concept of operative scheme (Soressi and Geneste, 2011 and references), technological features are described taking into consideration the morpho-technological identification of individual links in the different chains of action recorded in each site to examine how these might have been affected- or driven by -the circumstances in which the lithic materials were found (outcrop, detrital or *in situ* gathering; clast abundance, size, quality and shape/s). Following through on the chains of action, we examine the cause-effect relationships of these raw material's variables in terms of the gestures used by the hominins during the stone reduction processes and the technical strategies they chose. Traditionally, these observations are useful to elucidate economic considerations, as well as giving information relative to hominin cognitive capacities (generally gleaned from an evaluation of the 'complexity' of the operative schemes thus identified).

Archeometry and attribute localization are also recorded for all items (e.g., percussion marks, retouch, fractures; Laplace, 1974). In pace with deepened interests in percussive technologies during the Oldowan (for example: Assaf et al., 2020; Alperson-AfilGoren-Inbar, 2016; Arroyo et al., 2016, Arroyo and de la Torre, 2018; Barkai and Gopher, 2016; Diez-Martín et al., 2009; de la Torre et al., 2013, de la Torre and Hirata, 2015), we elaborated a special methodology to describe the specificities of the limestone macro-tools, both the non-flaked and the modified items (with or without traces of percussion; Barsky et al., 2015a). As well as being analyzed for their morpho-technological features, special attention is payed to the traces of percussion visible on the limestone macro tools (Barsky et al., 2015a; Titton et al., 2018), taking into consideration their position in relation to the volumetric features of the clasts, their dispersion and concentration and their localization in relation to the formal features of the surfaces upon which they are found (rounded surface, cutting edge, abrupt crest). This work is buttressed by experimental archeology in order to better understand the kinds of gestures and materials used by the hominins (Titton et al., 2018).

For the flint and the limestone, cores and configured tools are subject to morpho-technical analyses taking into account the features of the original clast, main percussion platform and technique (Rodríguez, 2004; Toro-Moyano et al., 2010). Exploitation strategies are determined by defining the core type (Titton et al., 2021: Supplementary Material) and supported by diacritical analysis (Baena-Preysler and Cuartero, 2006; Titton et al., 2020) to determine management phases of cores and tools (Titton et al., 2020). Extension of the removals over the core/tool surface (Rodríguez, 2004; Titton, 2021), order and type are also analyzed (Barsky et al., 2015a; Titton et al., 2020). Among the more innovative strategies, statistical analyses have been used to determine angle amplitude variability separating the facets on core tools in the identification of sub-spheroids at the BL site (Titton et al., 2020). Measurements were taken using geometric morphometric analysis of 3D models (available from Titton et al., 2020: https://sketchfab.com/TITTONETAL2019). Flakes and retouched flakes, are analyzed through mainly classical morpho-technological methodology grounded in the concept of operative schemes (Soressi and Geneste, 2011 and references therein). Core management phases are supported by flake analyses (Toth, 1985), considering residual cortex on dorsal surfaces as well as removal negative direction and number (Castañeda, 1999; Titton et al., 2021: supplementary material). Finally, fragments are analyzed in terms of their raw material, size and shape to determine production method (bipolar-on-anvil, free-hand or other).

Our holistic approach to lithic studies incorporates multidisciplinary data from studies of site formation processes and post-depositional disturbances undergone by the sequences and the artifacts they contain (Titton et al., 2021). This strategy has proven to be considerably useful to understand the life-stories of the lithics. Varying states of conservation are defined by evaluating surface alterations, as well as the presence/absence and dispersion of patina (Zaidner, 2013; Barsky et al., 2015b; Titton et al., 2018; Titton et al., 2021; Titton, 2021). Lithic taphonomy informs about the displacement of artifacts within the site, either during or after their deposition. It has also proved important for evidencing possible re-use or recycling of individual lithics, for example, through the identification of pieces with different phases of patination (Toro-Moyano et al., 2010; Titton, 2021). In addition, systematic artefact spatial distribution on horizontal and vertical projections was carried out for the BL site using data from excavations up to the year 2018 (Titton et al., 2021). The aim of this work was to better comprehend the depositional sequence and the hominin activities within the site over time. This was facilitated by the elaboration of new and updated inventory databases for the Orce Pleistocene sites hosted at the Archaeological Museum of Granada (BL, FN3 and VM, Titton, 2021; Titton et al., 2021). During this process, we gathered the spatial coordinates for a total of 11,929 pieces excavated from the BL site from 1995 to 2018 and homogenized the data available from all of the excavations. Divergent denominations of the squares were normalized using data from the field diaries and fitted within the currently used standards. In some cases, however, information was found to be lacking from excavations dating prior to 2010, thus impeding their inclusion in our spatial analysis (Titton et al., 2021). This issue was further complicated by the fact that previous excavations considered the BL level 5 to be a single level (Turq et al., 1996; Gibert et al., 1998; Martínez-Navarro et al., 2005), while later advances made in our understanding of the evolution of stratigraphic and sedimentary contexts currently allow for more precision, dividing this layer into distinct depositional events. While Anadón and colleagues (2003) distinguished two different levels (D1 and D2), this information was not effectively integrated in the excavation strategies until 2010. In spite of this, the data analyzed (Titton, 2021; Titton et al., 2021) allowed us to reconstruct a surface of 148 m^2 and to study the spatial distribution of the lithic material and faunal remains on horizontal maps and vertical projections (effectuated very 1,000 mm) over most of the excavated area (Bargalló et al., 2016; Titton, 2021; Titton et al., 2021).

Our spatial analysis further benefited from information gleaned from our investigations into identifying refitting and conjoining lithic sets at BL (Toro-Moyano et al., 2013; Titton et al., 2021). The observation of the knapping axis of each product and the directions of the negatives, are clues to linking lithic items together in their operative order. As a first step in this study, we grouped the lithics into visually identifiable RMUs to facilitate our search for connecting pieces (Cziesla, 1990). More work needs to be done to further develop this informative aspect of our research, in particular at the FN3 site where, to date, undertakings to find spatial distribution of the artifacts and the search for refitting and conjoining lithic sets have yet to be carried out on a full scale.

4 RESULTS

The Oldowan stone toolkits from BL and FN3 are characterized by a differential use of the two main available raw materials: limestone and flint. Both of these rock types were collected locally from the Jurassic age formations enclosing the sites. Over the years, different kinds of lithic studies have been undertaken on the two archeological collections, focusing at first on techno-typological and petrographic issues relating mostly to the flint items (Barsky et al., 2010; Toro-Moyano et al., 2010), while such a detailed petrographic analysis of the limestone has yet to be carried out. Early on, a dichotomous use of these two materials was made evident, with the limestone items being significantly larger-sized and the flint component marked most notably by the-typically Oldowan profile of small-sized cores and flakes ranging on average between only 2 and 3 cm in maximal length. Cut marks and traces of percussion observed on some of the large mammal remains from the two sites (Espigares et al., 2019; Yravedra et al., 2021) confirmed the use of small-sized flakes for cutting meat off of the large mammal carcasses in a presumably scavenger-type subsistence patterning and the issues of primary access to carcasses have been raised in relation to interaction among which there would also be episodes of competition with other large carnivores present coevally at the sites (Espigares et al., 2013; Yravedra et al., 2021). Compared with the relatively easy readability of the flint items, the limestone pieces present in the assemblages pose more interpretative

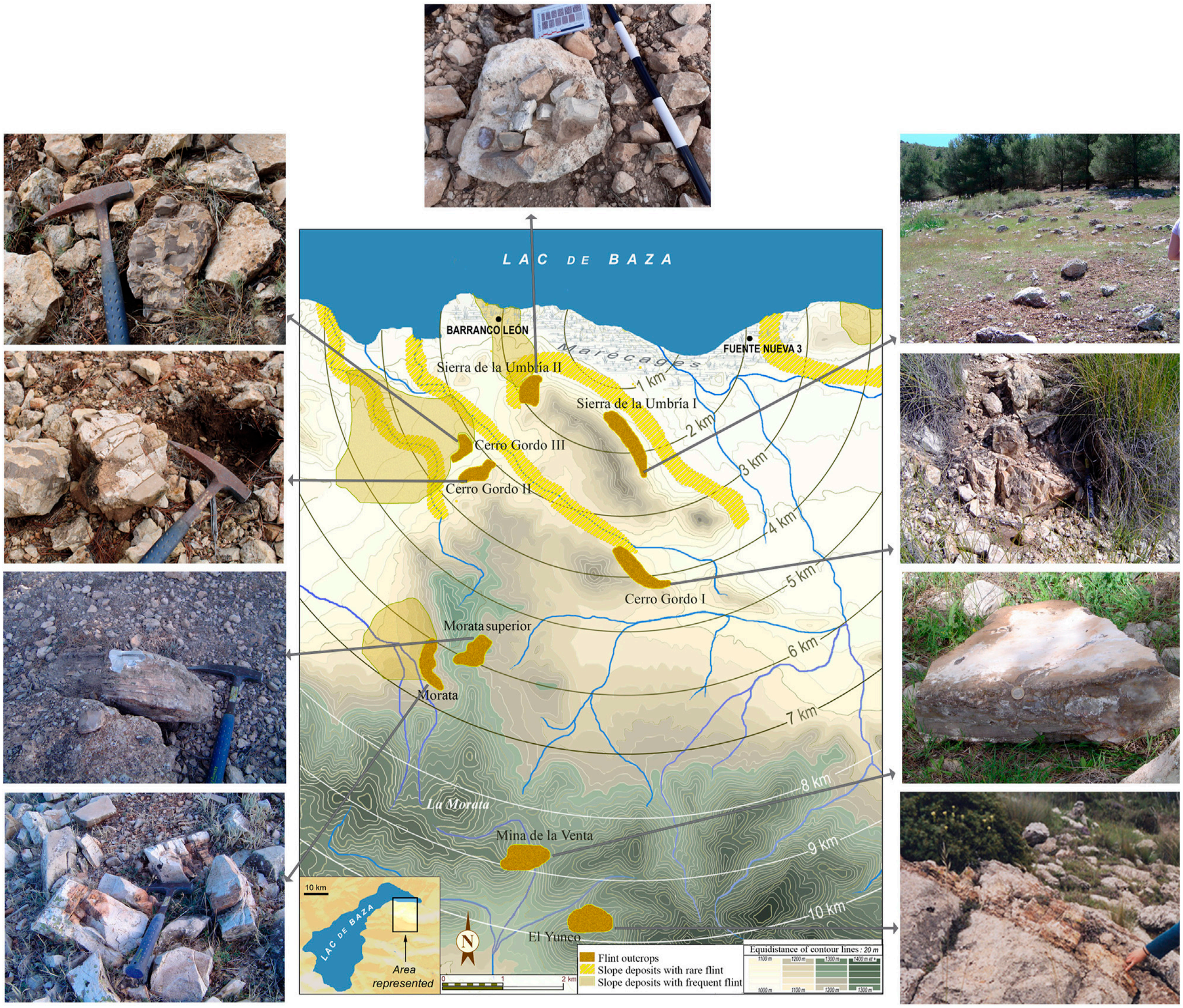

FIGURE 4 | Map showing the location of the flint outcrops and block morphology (modified after Toro-Moyano et al., 2010).

difficulties, especially due to their highly non-standardized morphologies and also to the alteration of their weathered surfaces. The natural presence of the limestone clasts within both of the sites complicates matters only further, making exact quantification of manuports or simply 'used' items virtually impossible. Finally, from 2010 onwards, a new impulse was given to the study of the limestone component of the assemblages, especially as interests in percussive activities in relation to Oldowan toolkits was increasingly growing as a pathway to better understanding the kinds of activities being performed by our hominin ancestors (Barsky et al., 2015a; Titton et al., 2018 and references). Thus, new studies have come to reveal that the Orce limestone toolkits contain not only cores and flakes, but also a relatively high diversity of tools, all relating to some form of hammering or pounding activities (active or passive). The toolkits have now become references in terms of categorizing the different types of traces of percussion thanks to an exceptionally wide array of types (defined both experimentally and archeologically) on used, knapped and configured items (Barsky et al., 2015a; Barsky et al., 2018; Titton et al., 2018; Titton et al., 2020).

Of course, the study of hominin comportments with respect to the rock types they were using goes hand in hand with other aspects of lithic analyses, in particular typological and technological considerations. In the framework of the present study, we begin with a presentation of a synthetic description of the toolkits from BL and FN3, emphasizing this special aspect of raw material's dichotomy (limestone and flint) and highlighting: 1) The availability and formal aspects of the raw materials in the landscape; 2) Tool type distribution at each site according to raw material's allocations; 3) Main morphometric features of the tool categories; 4) Reduction strategies identified for each raw material; 5) Behavioral patterning: potential uses proposed for the limestone and flint toolkits. Because numerous publications

TABLE 3 | Identified flint outcrops with their lithostratigraphic position, referential flint type denomination, block morphology and distance to the Barranco León and Fuente Nueva 3 Oldowan sites.

Outcrop Name	Lithostratigraphic Position	Flint Type Denomination	Block Morphology	Distance to BL & FN 3
Cerro Gordo I	Dogger	SFN1, SFN2, SFN3, SBL2, SBL3	Slabs, Lenticular blocks	4 Km to BL 3,5 Km to FN3
Cerro Gordo II	Dogger	SFN1, SFN3, SFN4, SBL1, SBL4	Slabs, blocks	2.8 Km to BL 5 Km to FN3
Cerro Gordo III	Dogger/Malm	SFN1, SFN2, SFN3, SFN5, SBL2, SBL3	Slabs, beds	2 Km to BL 5,2 Km to FN3
Sierra de la Umbria I	Dogger	SFN2, SFN3, SFN5, SBL2, SBL3	Slabs, beds, blocks	2.3 Km to BL 2,2 Km to FN3
Sierra de la Umbria II	Dogger	SFN2, SFN3, SFN5, SBL2, SBL3	Nodules, beds	1.2 Km to BL 3 Km to FN3
La Morata	Dogger	SFN1, SFN3, SFN4, SBL2, SBL3	Bedded blocks, nodules	6 Km to BL 6, 5 Km to FN3
La Morata superior	Dogger	All types	Slabs, beds, blocks	4.5 Km to BL 5 Km to FN3
Mina de la Venta	Dogger	SFN1, SFN2, SFN3, SBL2, SBL3	Slabs, bedded blocks	9 Km to BL 9 Km to FN3
El Yunco	Dogger	SFN1, SFN2, SFN3, SBL2, SBL3	Beds, blocks	10 Km to BL 10 Km to FN3

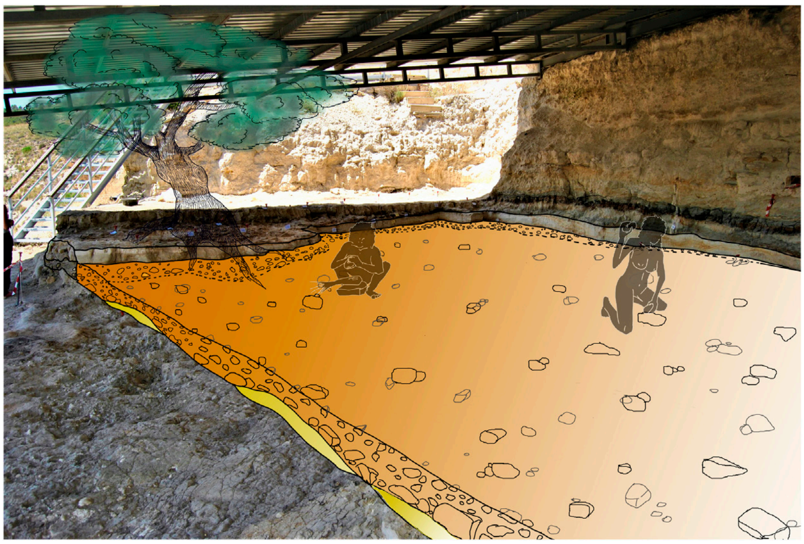

FIGURE 5 | Illustration of hominins exploiting lithic raw materials contained within layer D1 of the Barranco León site (drawn by S. Titton, Titton, 2021).

are available explaining the different tool categories and their typo-technological features (above-referenced), our focus here is on aspects relating hominin behavior to lithic raw materials and how this data has underpinned some significant differences between the BL and FN3 sites. Finally, the behavioral patterns identified are compared and contrasted with those known from other Eurasian Oldowan occurrences, in order to expand our discussion towards a wider picture of the European Oldowan and the adaptive and social practices of its little-known hominin artisans.

4.1 The Availability and Formal Aspects of the Raw Materials in the Landscape

The lithological surveys carried out between 2004 and 2006 (Toro-Moyano et al., 2010) and completed more recently (2022) have allowed to precisely assess the flint and limestone resources available in the immediate environment of the sites to within a radius of approximately 10 Km. Lithics were gathered mainly from detrital sources situated to the south of the sites in the Sierras of Orce and Maria, between the depression of the Baza paleolake to the north, and the formations of the Passillo de Chirivel to the south. In this context, 9 outcrops in primary position in Jurassic formations, mainly located in the Dogger, were geo-located, described and sampled and each of them was related to secondary deposits containing the same type of material in detrital position in the Quaternary slope deposits of the post-orogenic Chirivel basin. In total, nearly 20 localities were recognized and sampled within a radius of 10 Km (**Figure 4**). Each of these outcrops offers different types of flint in variable quantity, quality and morphology. Most of these types correspond to those identified in the lithic series of the two nearby Oldowan sites (**Table 3**).

The most abundant facies, recognized in most of the outcrops, is gray oolithic flint. However, it is not the one most selected for knapping at BL and FN 3. In terms of morphology, the Dogger flints outcrop mainly in the form of relatively thick plates (between 10 and 20 cm thick) in beds (between 30 and 40 cm), very frequently in the form of fractured tabular blocks depending on the layering of the rock, and more rarely in the form of a lenticular block. These siliceous accidents result from a diagenetic evolution of micritic carbonate deposits rich in bioclasts and appear in various forms of more or less oolithic marine flint and sometimes jasperoid of green, orange-yellow, or even red color (Baena Pérez et al., 1979). The main facies used by the hominins are accessible within a radius of 4 Km in primary and secondary position. Some secondary deposits are very close to the sites or even on the site in the case of BL, located at the mouth of a ravine rich in blocks of flint transported naturally in the slope deposits from the primary outcrops of the Sierra de la Umbria, towards the depression of the Llano de Almaida (**Figure 4**).

Even though the raw materials used at BL and FN3 were immediately available in or around the sites, we can still identify very significant differences in the contexts in relation to how these rocks were collected and used, as well as interesting economic and behavioral aspects. As we have recently shown, the Barranco León site constitutes a unique Oldowan context underlining, for the first time, the important role played by rock availability for hominins choosing their place of occupation. A combined approach of lithic analyses, taphonomy and refitting, combined with artifact spatial distribution and geology, has provided an explanation for the existence within this site of very fresh and very weathered/rolled bones and artifacts (Titton et al., 2021). According to this interpretation, the erosive surface of archeologically sterile level C was buried during a high energy flash flood depositional event (level D1) that brought a dense layer of limestone gravels, pebbles and cobbles, as well as flint nodules, into the site from a previous depositional situation located nearby to the south (see **Figure 2** in Titton et al., 2021). This event also forcibly brought in fossil bones and even knapped lithics, whose transport during this intense episode rendered them even more fragmentary, even as they endured taphonomic damages. Subsequently, a second episode occurred, characterized by the arrival of hominins to the site-perhaps attracted to this natural accumulation of limestone cobbles and flint nodules -upon which surface they performed a range of pounding, knapping and butchery activities (**Figure 5**), leaving behind a well-preserved lithic record with complete operative chains (and some refitted lithic items). This anthropic surface was subsequently covered by the *in situ* gradual sedimentary event corresponding to level D2 (which also contains archeological materials).

Given this, very unique, situation at BL, we have proposed (Titton et al., 2021) that the raw materials used in the toolkits were mostly collected from directly within the deposits themselves (level D1). Thus, the limestone component of the BL assemblage is entirely composed of slabs and cobbles. The flint, outcropping only some 1.000 m away to the south and gathered from its detrital position in the BL deposit (weathered nodules) and in the form of previously knapped items, was knapped or re-knapped (present of double patina) into the desired small-sized flakes. That knapping took place *in situ* is attested by complete operative chains and the presence at this site of very abundant tiny flakes and fragments (62.5% % of the BL assemblage, Titton et al., 2021) that we have found experimentally to be produced during knapping operations with the Orce flint (Toro-Moyano et al., 2010) that tends to be brittle and accidented.

The gathering of raw materials and economic comportments at the nearby FN 3 site were clearly somewhat different. There, hominins chose predominantly to exploit the limestone outcropping abundantly and even encasing the site; mainly in the form of blocks. Our surveys to study these outcrops revealed generally silicified limestone, presenting good mechanical quality for knapping. Limestone blocks were thus selected by the FN 3 hominins, who may even occasionally have mined-out choice materials from the outcrops (although this has not been clearly demonstrated so far). In addition, hominins exploited limestone cobbles from an unknown (but probably nearby) source. So far, agricultural activity in the vicinity of the FN 3 site has made the exact localization of this potential cobble source difficult to identify. However, given the actual situation of the Baza sector of the GBB and what is known about the paleo lake and its fresh water (thermal) sources (García-Aguilar et al., 2014), we may safely assume that (as today) the existence of a fresh water-hole scenario at FN 3 provides strong reasoning for understanding why this area attracted such a large array of fauna (including mega herbivores) and of course, hominins. In contrast to level D1 at the BL site, at FN 3 the depositional sequence is in primary context. In anthropic level 5, where conditions were considerably colder and dryer than at BL (level D1), we can envisage the hominins moving synchronically through the landscape alongside the other animals; each species taking advantage of the same, favorable conditions for life: namely, the presence of fresh water on the shores of the saline lake Baza.

In spite of the changing climatic contexts affecting the site and the shifting lacustrine and palustrine environments recorded there, this *in-situ* accumulation was affected by post-depositional alterations caused mainly by the nature of the sediments themselves (i.e., hydro plastic deformations of the clays, loss of integrity and erosion of the sands), as well as such gravitational alterations (i.e., sloping) and faulting. In spite of this, most of the herbivore and carnivore fossils are found with at least some anatomical connection still in place. In fact, an incomplete *Mammuthus meridionalis* carcass exhumed during excavations in 2001 and 2003 is described (Espigares et al., 2013). Currently, the most outstanding expression of level 5A is a thin carbonated crust containing a high concentration of firmly compacted mega to large mammals and some carnivores, as well as some sparse lithics. This unique Oldowan floor certainly represents a very long period of time when animals and hominins were gathering around this watering hole to drink and to consume plant and meat resources. Comparatively, the sedimentary package of the (older) anthropic level 2 (greenish clays), corresponds with milder, and more humid climatic conditions (Oms et al., 2010; Oms et al., 2011; Sánchez-Bandera et al., 2020). While its contents appear analogous to those of level 5 (it remains to be archeologically explored over a larger surface area), the anthropic signal appears somewhat stronger in level 2 because of an apparently denser lithic accumulation that we hope to explore further in the upcoming years. Flint resources, while available nearby in detrital position (the flint outcrop is situated ~2.000 m to the south of FN 3), were doubtless somewhat harder to come by

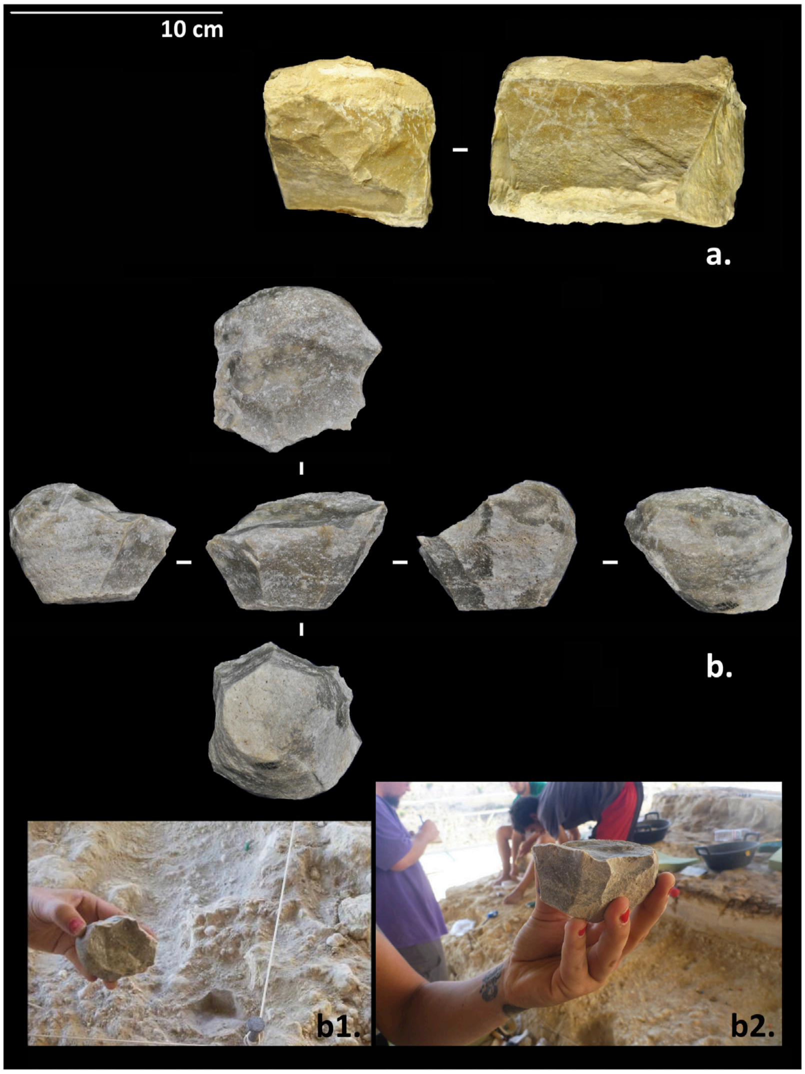

FIGURE 6 | (A) Large-sized flint clast from Barranco León (120 × 90 × 75 mm) (after Titton et al., 2021). The presence of this item in the depositional sequence flash flood event of level D1 demonstrates that at least some large-sized flint clasts were available to the hominins occupying the site. In spite of this, they continued to prefer limestone for their heavy-duty, percussive activities and systematically reserved flint for knapping small flakes; **(B)** Exceptionally large recurrent unidirectional knapped core with a perpendicular invasive surface removal (74 × 68 × 52 mm) **(B1)** Large flint core and its *in situ* imprint in level D1 and **(B2)** General view of the large flint core discovered in level D1 in 2018 (Photos **(B1,B2)**: C. Sánchez-Bandera).

then at BL (see **Section 4.4** for discussion on how this affected the flint operative schemes).

4.2 Tool Type Distribution at Each Site According to Raw Materials' Allocations

Like the majority of Oldowan toolkits, both Orce assemblages are characterized by their non-standardized character; concerning both the macro (limestone) and the smaller-sized components (flint cores and flakes). Both toolkits contain very numerous limestone implements, identified as anthropically used or modified thanks to the presence of traces of percussion, knapping and/or (occasionally) shaping. The fact that the limestone clasts were present in the depositional sequences (a flash flood accumulated at BL and encasing limestone outcrops and blocks and cobbles at FN3) makes their exact quantification impossible (and pointless) and only the identification of systematic traces of use or modification (different from naturally induced marks) are reliable for registering the anthropic signal (Barsky et al., 2015a). In recent studies, the 'cataloguing' of repeated morphologies of traces of percussion has been successfully carried out, enabling us to identify a very wide array of percussion marks that point towards an equally wide range of pounding and hammering activities being performed *in situ* at both sites (i.e., accidental removal negatives, multi-facetted scars, crush marks, *piquettage*, cupula, Barsky et al., 2015a; Barsky

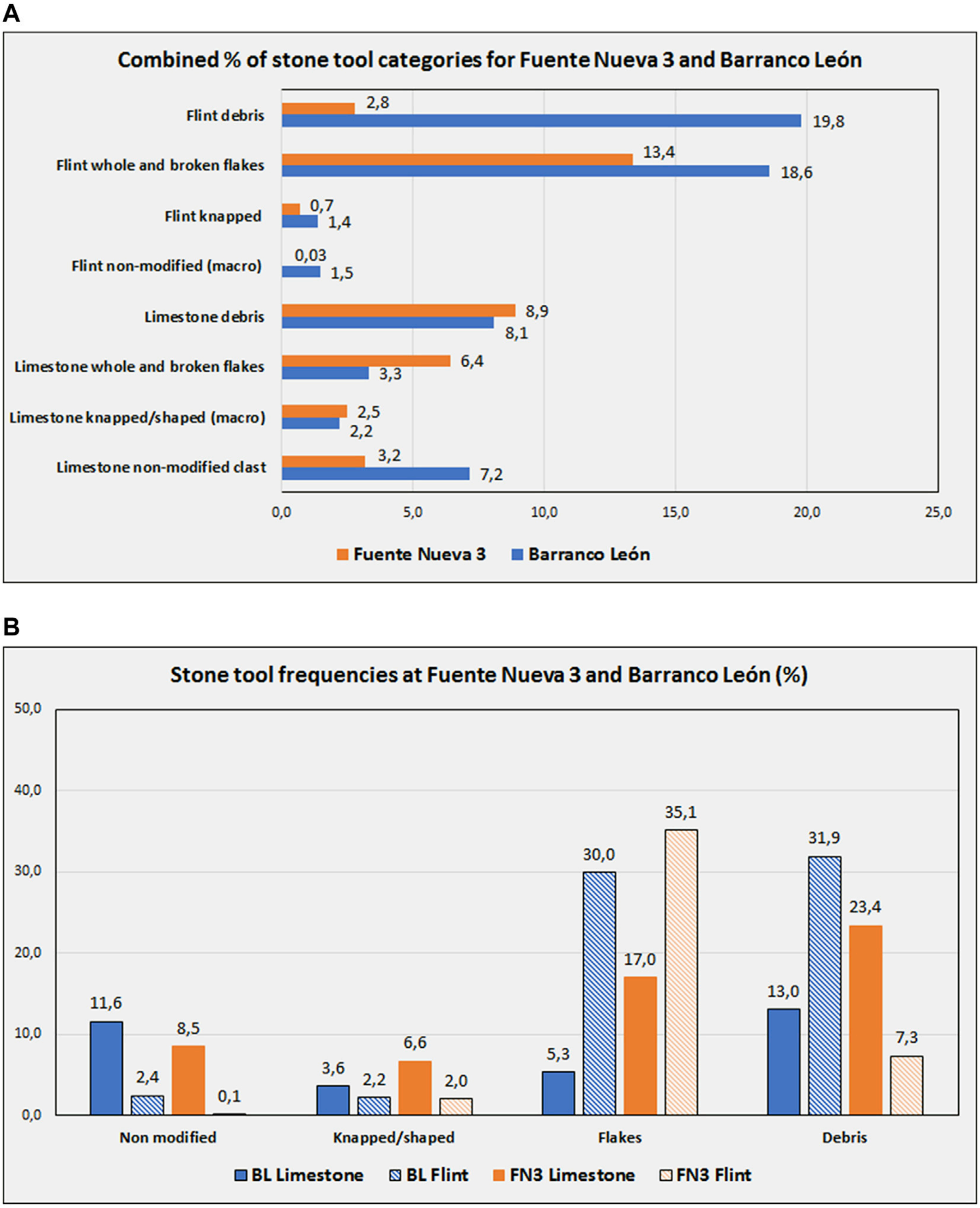

FIGURE 7 | Relative frequency of stone tool categories at Fuente Nueva 3 (FN 3) and Barranco León (BL). **(A)** The abundance of flint at BL relative to FN 3 is explained by its presence in the level D1 deposit. At both sites the limestone is well-represented in all categories, while flint shows higher frequencies among flakes and debris. The relative scarcity of flint debris at FN 3 could reflect a preference there for better quality flint. **(B)** Relative stone tool frequencies in accordance to rock types at BL and FN 3. The limestone is well-represented in all categories and dominates in the non-modified and shaped/knapped groups. Relative frequencies of flint flakes and debris illustrate the preferential use of this rock for knapping.

et al., 2018; Titton et al., 2018). In addition, the anthropic nature of the scarring observed on the limestone has been confirmed by the findings of volumetric 'regularity' in their positioning on the cobbles and blocks (in relation to their size, weight, and geometrical features). Finally, experimental research has explored the possible or probable activities (and their associated gestures) that specific sizes and shapes of percussive tools might have been used for, taking into account the kinds of materials most likely to have been available to the hominins present at the sites (i.e., wood, plant resources, tendons, bones, Barsky et al., 2018;

Titton et al., 2018). So far, our results show that at least some of these tools were effective for working soft materials (such as tendons) or for chopping wood (activities poorly identified in Oldowan sites where generally only butchery has been recognized).

There remains much to learn about the function of the limestone pounding tools and we continue to explore this theme with additional experimental work that will, in future, benefit from complementary micro-trace analyses. Optimal results and successful interpretations of tool functionality based on microscopic trace research is however, more effectively achieved from flint and, it is unlikely to obtain such high-resolution information from the altered limestone surfaces and edges. This is particularly true at BL, where limestone cobble tools often present a higher degree of alteration than at FN3, even reducing some items to no more than a powdery remnant of the original clast. Contrastingly at FN3, some of the silicified limestone tools (in particular cores and flakes) do show relatively good preservation and we hope in future to explore the possibility of performing high resolution use-wear analyses on these materials.

On the whole, clearly configured limestone tools are extremely rare. Concerning our investigative strategy however (since 2010), laying out and arranging each of the limestone collections in accordance to their main features (size, contour and section, knapping arrangement or absence thereof, etc.) was useful to recognize some repeated morphotypes. We identify pieces with strong volumetric and geometric similarities that, in some cases, even suggest a sort of 'local' standardization- or at least, some kind of mental template (Barsky et al., 2015a; Barsky et al., 2018; Titton et al., 2020). We believe that the (rare) pieces that display both morphometric and technological similarities could indicate that the hominins were using selective criterion both in their gathering of the clasts and in their technological and gestural choices. Thus, they selected the most appropriate limestone clasts (cobble or block) for making some specific items, subsequently shaping them with some intentionality in terms of their manufacture (likely in relation to a particular task). However, the specific shapes, sizes and mechanical qualities of the Orce limestone were determinant factors for the final morpho-technological outcome to such a degree that we rarely find the same items in other collections. In spite of this, a few items have been identified as fitting with the morpho-technological definitions of known Oldowan tool 'types', such as heavy-duty scrapers (present at both sites, Barsky et al., 2018) and some sub-spheroids (identified so far only at BL, Titton et al., 2020).

The lack of flint macro tools or hammerstones at both of the Orce sites (**Table 1** and **Figure 6**) *in spite of the availability of large-sized flint clasts* (either from nearby outcrops or within the depositional sequence-as at BL) demonstrates *an obvious mental link between limestone and heavy-duty percussive activities*. Conversely, such a link is equally established for the flint, which was exclusively used for the production of small flakes. It thus appears obvious that the hominins were not only capable of adapting their knapping strategies to the morphology and mechanical properties of the available raw materials, but also that they selected their raw materials in relation to the desired tools and tasks at hand. In spite of the preferential use of limestone for hammering and pounding (hammerstones, chopper-like tools and a few loosely configured items), the limestone assemblages show relative diversity, with toolkits also comprising a range of cores and flakes (described in **Section 4.4**). In fact, some tools show multiple and interchangeable phases of manufacture and use on single items (Barsky et al., 2015b; Titton et al., 2018; Titton, 2021; Titton et al., 2021). The distribution of the different elements composing the limestone assemblages at BL and FN3 indicate that these activities took place *in situ*.

The global type distribution (**Table 1**; **Figure 7**) allows to underpin subtle but significant differences between the two sites concerning flint exploitation. The clearest discrepancy between the sites concerns the relatively numerous tiny flakes and fragments at BL (many <1 cm), compared to FN3. A study carried out on these elements at BL evidenced that they display the same taphonomic duality observed on the larger lithic (and faunal) items, with some being very rolled, rounded and damaged, and others very fresh with sharp, angular edges (Cerezo-Sánchez, 2016; Titton et al., 2021). Given the interpretation of the depositional context at BL (Titton et al., 2021), we can explain this discrepancy by suggesting that the abundant tiny lithics actually form a part of the sedimentary context of level D1 while, contrastingly, the fresh items bear witness to on-site stone knapping and use on the surface of the raw material reservoir deposit (level D1). Tiny lithics present at FN 3 also attest to *in-situ* lithic manufacture and use, while their relative scarcity in level 5 could reflect a smaller number of acting individuals in relation to the very long time period likely represented by the accumulation; as supported by the micromorphological studies in progress. This relative paucity at FN3 may also reflect the findings of some of the flint-knapping activities taking place off-site and an apparent preference for better quality flint clasts.

Other behavioral aspects can be gleaned for each raw material from the relative distribution of cores and flakes at the two sites. Their proportional relationship is higher at BL, where a relative abundance of cores is noted compared with FN 3. These relationships must be considered in different ways. Looking first at the limestone, it is important to contemplate the different phases of research leading to their recognition as an integral and even dominant aspect of the assemblages. The presence of natural clasts in the deposits at both sites, as well as their varying degrees of surface alteration and a majority of only very summarily modified (or simply used) pieces, all contribute to their overall interpretative complexity. At FN 3, where some levels are characterized by whitish limestones and sedimentary contexts containing gravels and other clasts that can easily be confounded with anthropically used or modified pieces, the paucity of limestone flakes could be due (at least partially) to difficulties in on-site identification. Of course, the impetus given to the study of the limestone at both sites for over a decade now has led us to improve our strategies, guaranteeing the presence of a lithic specialist at all times during excavations, to assure recognition and proper identification based on knowledge we have gained, in particular, from our experimental research. A relative paucity of cores compared to flakes and fragments can be explained by both contextual and behavioral reasons. As we have seen, the hominins at BL were particularly interested in stone

TABLE 4 | Dimensional features of the different tool categories from Barranco León and Fuente Nueva 3 in accordance to the two main rock types. Thickness was a constant for cores on flakes in limestone from BL.

			Length		Width		Thickness	
		N	**X**	**SD**	**X**	**SD**	**X**	**SD**
BL FLINT	**FLAKES**	221	26.07	11,711	19.29	9,147	8.00	5,295
	DEBRIS < 5 mm	491	8.78	5,500	6.10	3,817	3.92	2,786
	CORES	21	46.62	27,220	34.05	21,386	25.95	19,893
	CORES ON FLAKE	3	42.33	13,013	26.00	10,392	16.00	1,000
BL limestone	**FLAKES**	17	26.82	11,897	23.59	12,390	10.12	6,421
	DEBRIS < 5 cm	106	15.01	10,044	11.60	8,126	8.04	5,941
	DEBRIS > 5 cm	131	106.61	35,412	76.00	26,462	48.16	19,473
	CORES	54	84.57	22,740	67.87	16,147	47.39	15,769
	CORES ON FLAKE	2	51.00	12,728	35.00	7,071	*	*
	HAMMERSTONES	44	109.41	49,822	84.27	36,008	58.59	22,804
	WHOLE NMC	214	93.51	34,582	71.15	26,427	46.01	19,764
FN3 FLINT	**FLAKES**	263	28.37	12,455	21.70	9,048	8.14	4,804
	DEBRIS < 5 mm	106	14.76	8,872	9.08	5,623	5.86	4,058
	CORES	9	45.22	9,189	36.00	7,937	28.00	11,136
	CORES ON FLAKE	15	41.87	16,128	29.73	14,611	14.87	5,566
FN3 limestone	**FLAKES**	105	34.32	19,880	28.27	17,224	12.32	9,293
	DEBRIS < 5 mm	294	17.15	10,269	13.04	8,596	9.04	6,163
	DEBRIS > 5 mm	60	81.43	31,335	60.88	23,476	45.58	17,553
	CORES	80	81.25	29,549	61.38	21,764	45.51	16,051
	CORES ON FLAKE	2	21.50	4,950	17.50	0.707	10.00	2,828
	HAMMERSTONES	48	91.40	36,522	69.29	27,628	53.42	19,521
	WHOLE NMC	63	58.75	38,519	46.81	27,275	33.79	21,683

**NMC, non-modified clasts. Bold letters in table indicate site names, column headings and codes.*

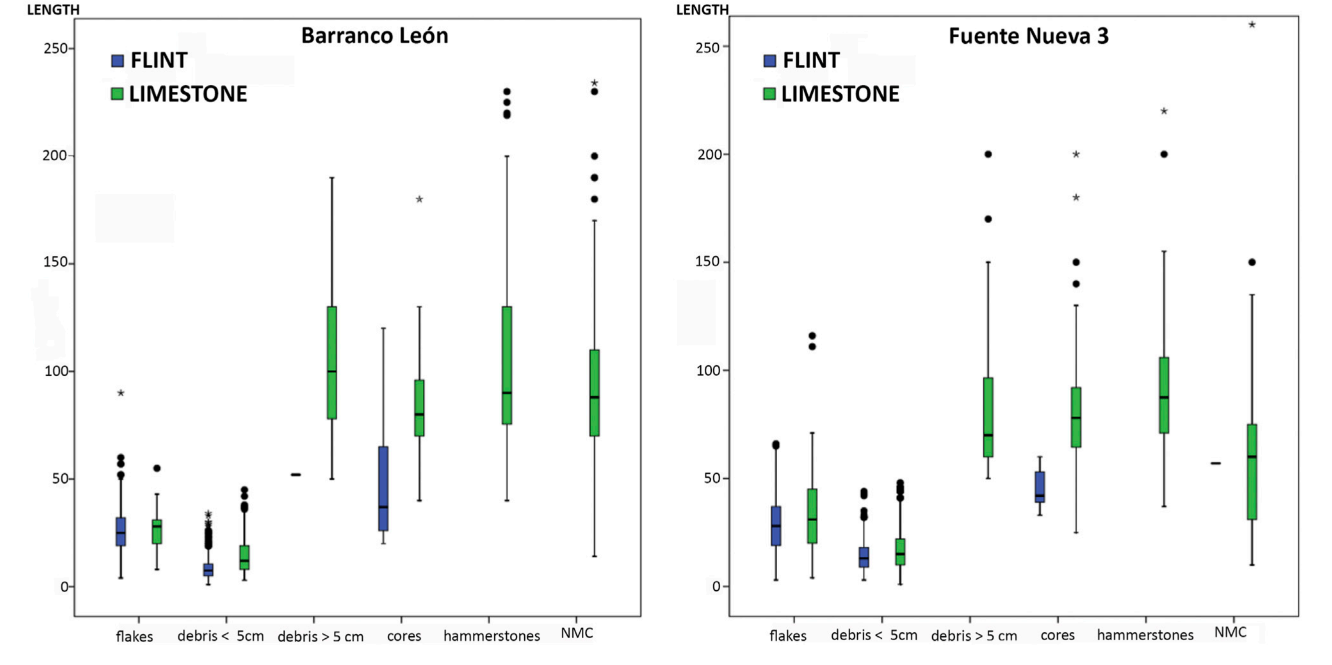

FIGURE 8 | Boxplot for the length of the main categories in BL (left) and FN3 (right): flakes (only complete), debris <50 mm, debris >50 mm, cores, hammerstones and non-modified clasts (NMC).

processing and maybe even occupied the site to take advantage of the ready availability of limestone and flint clasts in all shapes and sized (a virtual lithic supermarket!). Knapping was one of their principal activities and a number of flint cores are added to the collection as a part of the flash flood event (level D1). Some of these even display double patina, attesting that they were re-knapped during this occupational phase. Meanwhile, in the primary contexts at FN 3, hominins would have looked for detrital flint clasts in the immediate vicinity of the site. They even brought in some larger-sized flint flakes to site (Toro-Moyano et al., 2010), where they were expediently knapped to obtain the desired format of small flake (secondary knapped flakes: Zaidner, 2013; Barsky et al., 2015b). Moreover, selection has been suggested at FN3 concerning the flint, with a preference demonstrated for the finer quality with the most homogenous grain.

4.3 Main Morphometric Features of the Tool Categories

We analyzed the measurements (length, width, and thickness) of the lithic items in the assemblages of BL and FN3 (non-modified clasts, hammerstones, cores, flakes, debris <50 mm and debris >50 mm), calculating the mean and standard deviation for each group. The difference of the means was evaluated by T-Student Test, with a critical level of statistical significance of $p < 0.05$. For each site, we have explored the metric differences between tool categories and raw materials (**Table 4**; **Figure 8**).

All the non-modified clasts are only in limestone. In BL, the numerous natural cobbles have variable sizes, while at FN3 there are fewer and they are considerably smaller (BL = 93.5 × 71.1 × 46 mm and FN 3 = 58.7 × 46.8 × 33.7 mm). The difference in the means is statistically significant ($p < 0.05$). Additionally, all of the hammerstones in our samples from both sites are also only in the hammerstones from BL appear slightly larger than at FN3 limestone (BL = 109.4 × 84.2 × 58.5 mm and FN 3 = 91.4 × 69.2 × 53.4 mm), and the mean size ranges were found to be significantly different in width ($p < 0.05$) but not in length ($p = 0.053$) or in thickness ($p > 0.05$).

At BL, the average limestone core size is considerably greater than for the flint (BL: limestone cores = 84.5 × 67.8 × 47.3 mm and flint cores = 46.6 × 34 × 25.9 mm). The results for FN3 are very similar (FN 3: limestone cores = 81.2 × 61.3 × 45.5 mm and flint cores = 45.2 × 36 × 28 mm). Core size differences are statistically significant for both sites ($p < 0.05$ in all cases), perhaps due to the smaller size of flint nodules compared to the bigger limestone clasts available, or to a more intensive exploitation of the flint cores. At an inter-site level, no differences were found between flint cores from both sites ($p > 0.05$ in all cases); although they are scarcer and more homogeneous at FN3 (showing much less variance than the BL flint cores). The limestone cores do not show statistically significant size differences ($p > 0.05$ in all cases), although for FN3 the size range is greater and outlaying limestone cores can be found (both smaller and bigger).

At BL, the average size of the flint flakes is 26 × 19.2 × 8 mm and the average size of the limestone flakes is 26.8 × 23.5 × 10.1 mm, with no significant differences noted ($p > 0.05$ in all cases). At FN3, the average limestone flake size is 28.3 × 21.7 × 8.1 mm and the average limestone flake size is 34.3 × 28.2 × 12.3 mm, with the differences being statistically significant between the two raw materials for this site ($p < 0.05$ in all cases). At an inter-site level, no statistical differences were found between limestone flakes ($p > 0.05$ in all cases), but the small sample from BL could be affecting the analyses. The small difference in average for the flint flakes between sites is statistically significant for the length and width ($p < 0.05$), underpinning the small flint component of the BL assemblage. The debris <50 mm are very abundant at BL, enhanced by very small flint ones (BL flint = 8.7 × 6.1 × 3.9 mm) and statistically differentiated ($p < 0.05$ in all cases) from the bigger limestone debris (BL limestone = 15 × 11.6 × 8 mm). At FN3, the flint debris <50 mm (FN3 flint = 14.7 × 9 × 5.8 mm) are also significantly differentiated ($p < 0.05$ in all cases) from the bigger limestone debris (FN 3 limestone = 17.1 × 13 × 9 mm). Meanwhile, no differences were found for the limestone debris <50 mm between sites ($p > 0.05$ in all cases), while flint debris <50 mm from BL are significantly smaller than at FN 3. Concerning the length and width of the limestone debris >50 mm, there is a statistically significant difference between sites ($p < 0.05$) (BL = 106.6 × 76 × 48.1 mm; FN3 = 81.4 × 60.8 × 45.5) (**Figure 8** and **Table 4**).

Among the conclusions that can be drawn from these analyses, the lithic assemblage of BL is predominantly in flint and shows a clear dichotomy between raw materials: the use of flint is predominant in the small products of the assemblage, while the macro-tools are all in limestone. The importance of limestone is higher in FN 3 and, while the flint pieces are always small, the limestone items cover all size ranges, documenting not only limestone macro-tools, but also smaller items (especially limestone flakes and cores). This could be due to a choice of highly silicified limestone identified at the FN3 outcrops, which presents good mechanical quality for knapping.

4.4 Reduction Strategies Identified for Each Raw Material

A range of core reduction strategies are described in published studies for both the Barranco León and Fuente Nueva 3 sites (Toro-Moyano et al., 2010; Barsky et al., 2010). Meanwhile, our more recently published investigations have accented technological aspects of each site context (Barsky et al., 2015a; Barsky et al., 2015b; Titton et al., 2018; Titton et al., 2020; Titton et al., 2021). We summarize this information here for each site, relating it to the most outstanding feature that is: the dichotomous use of two main raw materials (limestone and flint).

Beginning with some points in common between the two sites and proceeding in the order of operative scheme outlined above, it suffices here to sum up our observations about the gathering and lithic raw material's contexts discussed in **Section 4.1**. Concerning the limestone, acquisition took place in the immediate vicinity of the sites. However, while only cobbles and slabs were used at BL, hominins at FN3 more often selected blocks than cobbles. Having not yet situated the exact

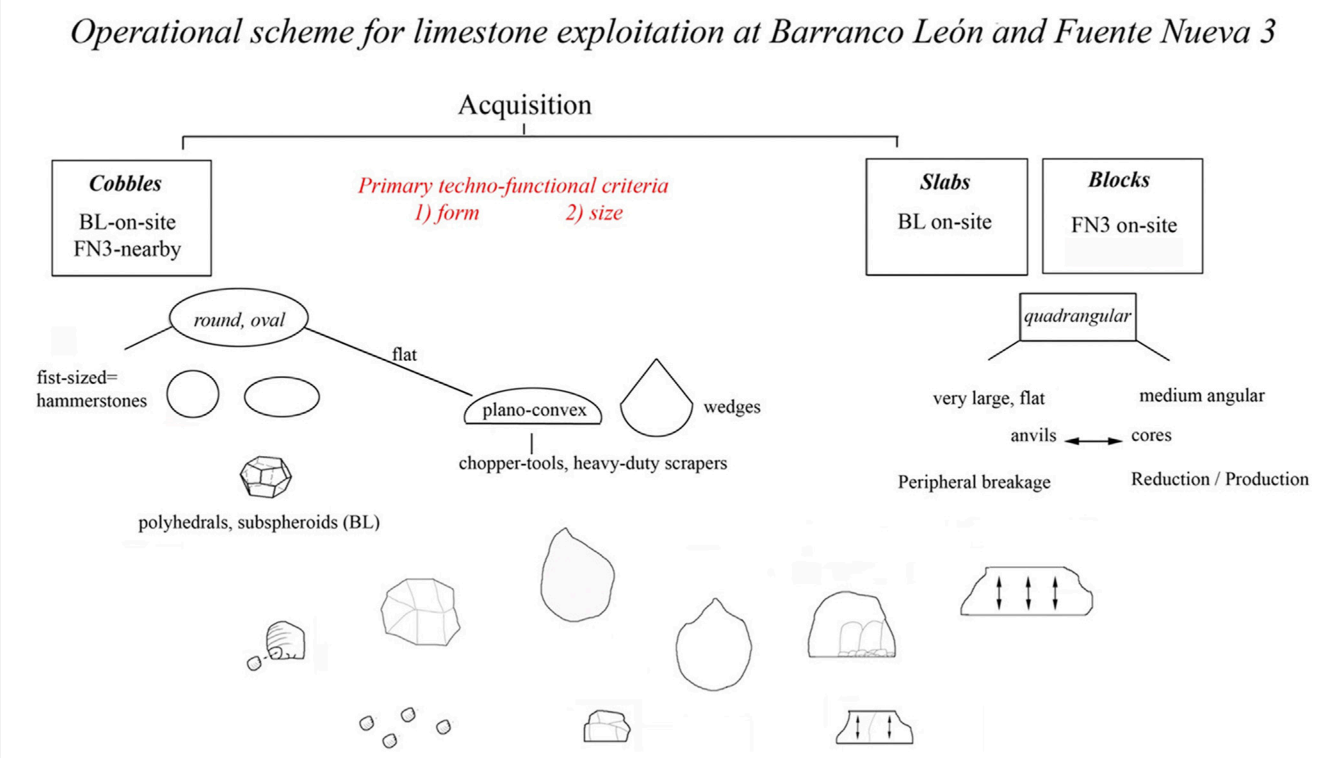

FIGURE 9 | Proposed operative schemes for the Barranco León and Fuente Nueva 3 limestone toolkits. Acquisition of clasts was in relation to primary techno-functional criteria (form and size). Typical use and/or reduction-production strategies revealing geometric morphometric choices relating to desired final product. A specific range of typical final products is identified (by D. Barsky).

provenance of these cobbles at or around the current FN3 excavation area, we might suggest that they were somewhat scarcer- or perhaps that cobbles of adequate shapes and sizes were not so readily available to the FN 3 hominins -as they were on the raw material rich pavement at BL. The FN3 hominins therefore exploited the (generally silicified and good quality) limestone blocks eroding out of the outcrops encasing the site. In both cases, limestone was available in a wide range of shapes and sizes and we have demonstrated that the choice of clasts was made in relation to the tasks at hand (Titton et al., 2018). Limestone tools used for pounding or hammering with or without modification were chosen in relation to their volumetric and morphometric features. Limestone cobbles used for flake production were more carefully selected for their quality (more silicified), as well as for the natural flaking platforms they offered (privileging parallelepiped forms). Hammerstones were (qualitatively) chosen for their compactness and present fist-size (or slightly larger) oval or rounded shapes. Slabs at BL might have served as anvils (Barsky et al., 2015a), although their highly altered surfaces impede confirmation of this hypothesis. Clearly defined anvils are conspicuously absent at both sites.

At both sites, we have identified the use of hard-hammer stone knapping using both free-hand and bipolar-on-anvil reduction methods. In some cases, we recognize the use of both methods on single items. While the bipolar-on-anvil method was more systematically used to reduce the small-sized flint nodules collected in and around the sites, it was also commonly employed to knap (and shape) the limestone clasts. Limestone clasts reduced using this method (generally of cubic shape) are occasionally recognized thanks to removal negatives with opposite impact points emanating from plane non-prepared platforms (cortex or fracture). Small-sized flint cores reduced in this way may present opposing impact traces; although our experiments have shown that this is not always the case. Flint products (flakes and fragments) produced by bipolar-on-anvil reduction also sometimes display opposite impacts, although this is hardly systematic and the method most often produces regular flakes (making quantification of bipolar-on-anvil products a meaningless exercise). Other 'typical' morphologies are bullet-shaped forms and/or chunk-type debris. The possibility that the so-called "pieces esquillées", present in both assemblages (Toro-Moyano et al., 2010) could correspond to by-products of bipolar-on-anvil core reduction methods is presently being explored. Furthermore, our experiments suggest that some limestone pounding or percussion activities may have involved throwing or even block-on-block breakage (for example, for cobble opening); although these strategies need to be further supported with experimental archeology.

Limestone knapping strategies (**Figures 9**, **10**) were typically unidirectional recurrent, with the longer operative schemes

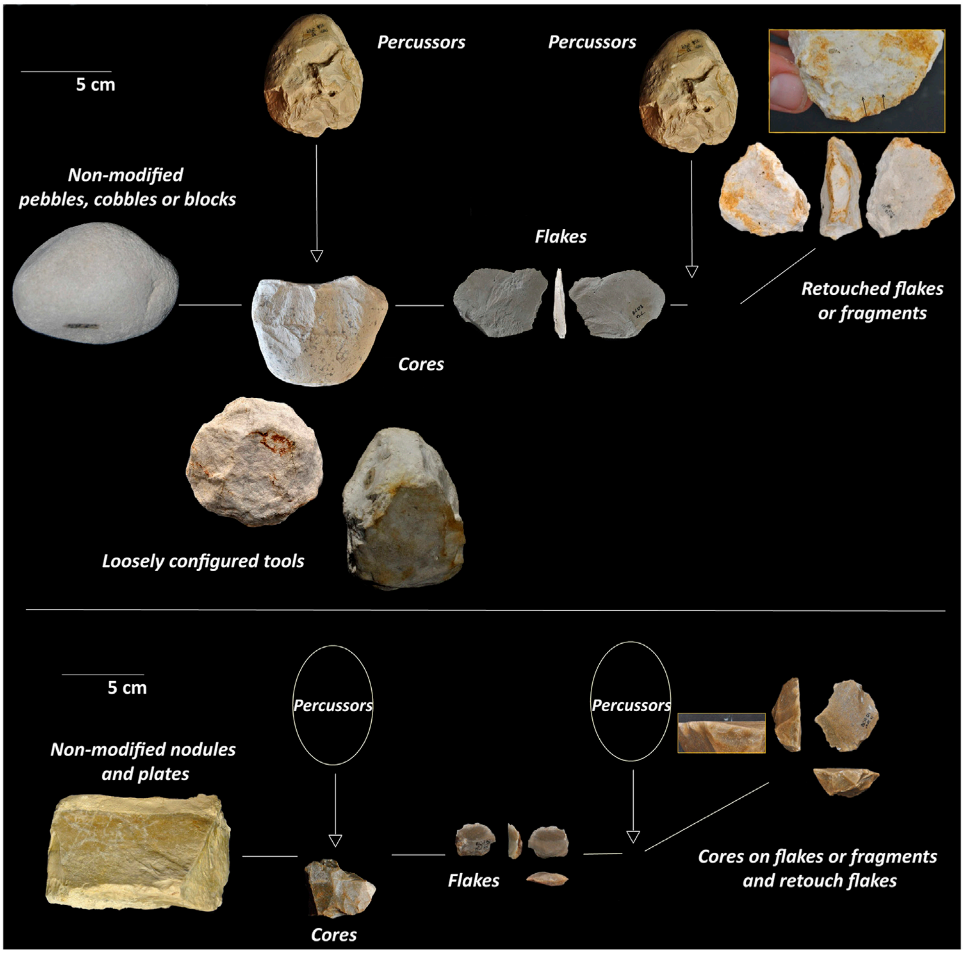

FIGURE 10 | Hypothetical limestone (upper) and flint (bottom) *chaîne opératoires* reconstructed from the Barranco León assemblage. Each category represents a distinct stage of production/use, taking into account a range of chains of action (Titton, 2021).

showing secondary phases of knapping using the platforms opened during this first phase. This was rarely, however, a multidirectional strategy (with core rotations after each removal or series of removals); but rather an orthogonal knapping tendency (the main method used at both sites to reduce limestone and flint). Multidirectional knapping has, however, been more specifically identified in the case of the sub-spheroids at BL (Titton et al., 2020). As at other Oldowan sites, centripetal strategies are incidental or absent and contingent on initial clast shape since non-prepared, generally cortical platforms were utilized with a gesture of recurrence (Barsky, 2009). Experimental flint knapping has revealed that many tiny flakes and fragments are produced from a single blow. This qualitative aspect of the Orce flint suggests that, given the overall scarcity of intentionally retouched tools and prepared platforms in the assemblages, the bulk of the tiny flakes (<2 cm) were most likely accidentally produced during knapping. Unlike for the limestone, multidirectional core forms observed among the flint at both sites result from the small size of the original nodules. There are also some cubic forms reduced using 'controlled bipolar-on-anvil' (as defined by Barsky and Lumley, 2010). While the limestone cores show shorter reduction sequences overall compared with the flint, some of the finer quality limestone (cobbles or blocks) does reflect longer knapping phases; sometimes resulting in core forms that appear more 'advanced'. Contrastingly, most of the flint cores display more exhaustive knapping series and these are present, for the most part, as small chunky fragments representative of the final phases of exploitation. This can be explained by the relative scarcity of flint compared with limestone in both site contexts.

Moving on to other observations concerning this last point that touches upon economic considerations in relation to the flint exploitation, interesting features are observed at both sites. At BL, where flint was collected directly in the pavement (level D1), one larger sized flint clast discovered in 2013 (**Figure 6A**.) does not display any signs of reduction or use: this is the only flint item discovered so far in this size range and situation. Its presence explains the existence of an exceptionally large-sized core (discovered in 2018, **Figure 6B**); the only one of its kind in the assemblage. To date, large-sized flint flakes that could correspond, for example, to this core, are not documented at BL, suggesting that some items may have been knapped and then transported off-site. So, whereas at BL even very rolled pre-knapped items were collected *in situ* and re-knapped on the surface of level D1 (Titton et al., 2021), at FN3 flint was collected a little further away and some larger-sized flakes were introduced into the site and re-knapped expediently to obtain the desired smaller flakes typical of the assemblage (Barsky et al., 2015b). All of these observations are in coherency with behaviors observed in operative schemes of the Oldowan techno-complex (**Figures 9,10**).

5 DISCUSSION AND CONCLUSION. RAW MATERIAL PROCUREMENT AND HUMAN BEHAVIOR AT BARRANCO LEON AND FUENTE NUEVA 3 IN THE CONTEXT OF THE EUROPEAN OLDOWAN

Despite the fact that our analyses of the origins of the lithic raw materials used at BL and FN 3 are revelatory of strictly local patterns of gathering associated with very little (or null) transport of the lithic clasts (Toro-Moyano et al., 2010), interesting behavioral dynamics are discerned. Meanwhile, even though different kinds of limestone and flint clasts were exploited at BL and FN3, a common denominator of stone reduction strategies is clearly identified and, we suggest, can be interpreted as truly representative of the European Oldowan with some, perhaps more advanced techno-forms (the spheroids, sparse retouched flint items and re-knapped flakes, more heavily reduced cores representative of longer operative schemes). The overall profile of the toolkits, while typically Oldowan, displays features that are specific to Orce (limestone tools with abrupt crests displaying use wear, abundance of percussive tools, alternating use of direct hammer and bipolar-on-anvil, multifunctional tools, etc.), mainly because of the particular characteristics of the raw materials that were used by the hominins occupying the area. So, while there is only very low (or null) standardization of the toolkits, these assemblages display their own characteristics in relation to other Oldowan sites, where different raw materials were used. Like other European Oldowan sites, however, the Orce hominins used a fixed set of knapping and shaping strategies that gave way to only a limited range of tool components: the small-sized flint flakes and the larger sized hammers, cores, and core-tools. The BL and FN3 archeo-paleontological occurrences are points in time and space around a saline lake in a dominantly humid but fluctuating environment, where hominins and other animals took advantage of water and rich animal and plant resources. At these sites, hominins performed not only butchery, but also a range of percussion-related activities; collecting, transporting, transforming and using local limestone and flint resources. At BL hominins obtained these materials by taking advantage of a natural lithic accumulation resulting from a flash flood event. At FN3, they exploited a natural source feeding the Orce wetlands to find limestone cobbles for hammering and pounding and also knapped silicified limestone blocks obtained from local outcrops. Flint nodules and flakes, also collected nearby, were brought to the site and expediently (re)knapped into small sharp products.

The BL and FN 3 toolkits present typically Oldowan features in line with other documented European Oldowan assemblages; with no standardized character of the artefacts dictated by opportunistic concepts (Arzarello et al., 2016). We identify: 1) tool types with recurrent morphologies (Titton et al., 2020) with evident use of their loosely configured structures (Barsky et al., 2018), in which we also recognize 2) tool multi-functionality; 3) multiple operational schemes (Titton at al., 2021, and **Figure 10**) and 3) selection of clasts in relation to primary techno-functional criteria (Barsky et al., 2015a; Titton et al., 2020). These features, along with selectivity of the raw materials, underpin that the hominins present in Europe during the late Early Pleistocene were skilled in their organization and technical management of resources. This highlights the existence of remarkable knowhow and defined mental conceptualization in the European Oldowan context (Barsky et al., 2018; Titton et al., 2020; Titton, 2021).

Comparing with data from other European Oldowan sites (age range = 1.6–0.78 Ma), (**Table 5**), we observe variability in the relative abundance of lithics composing each assemblage, relating to different factors, such as: site formation processes and excavation strategies, preservation conditions and taphonomic factors, site type and hominin *in-situ* activities. In some cases, factors relating to the collection- or not–of natural clasts that could have served non-modified for percussive activities remains problematic. The fact that most Oldowan sites are in open-air contexts and it is often impossible to determine their real extensions is also a limiting factor for determining the scope of hominin behaviors within each context. Finally, the kinds of raw materials available to hominins in and around each site also played a role in dictating the types of tools found and the technologies used to make them. Already however, hominins evidently chose knapping techniques in relation to the fracture-mechanical qualities of the materials available to them, adapting their strategies in accordance to the sizes and shapes of the clasts they used. From the settlement point of view, it is noted that, as in Africa (Howell et al., 1987; Hovers et al., 2008; Ashley et al., 2009; Hovers 2012; Stewart 2014), water-rich environmental contexts were favorable to hominin occupations in Europe (**Table 5**); assuring also a regular food supply. In spite of a dominance of open-air contexts, some variability in settlement patterns is observed, with some cave sites (Atapuerca Sima del Elefante TE9 and Gran Dolina TD6, the Vallonnet) and a basalt flowstone cavity (Bois de Riquet). In each territory, a regular water supply and food resources could indicate base camps or sheltered areas where activities always related to stone-knapping took place.

In each case, hominins adapted to the lithic resources offered by the occupied territory, recovering larger-sized clasts to use as percussion tools *in situ* (as at BL) and collecting from sources generally within a radius of 5 Km or less (**Table 5**). In most cases, flint was the preferred raw material for the smaller-sized cutting tools (flakes). The morphology of the clasts (nodules, plates, pebbles, cobbles, blocks) affected the morpho-technological features of the assemblages. The use of different materials in relation to tool manufacture is attested in various sites (e.g., BL, FN 3,

TABLE 5 | Site types and main lithic raw material's features at selected Eurasian Oldowan sites (in this table a single publication from which the information was obtained is cited for each site).

Site	Age	No of Lithics	Site Type/Setting	Lithic Raw Materials	Provenance	Selected Reference for Lithics
Barranco León	1.4 Ma	2,434	Open-air lacustrine, palustrine	Limestone slabs cobbles; flint nodules	*In situ*	Toro-Moyano et al. (2010)
Fuente Nueva 3	1.2 Ma	1,491	Lacustrine, palustrine	Limestone blocks and cobbles; flint nodules	0–5 Km	Toro-Moyano et al. (2010)
Pirro nord	1.6–1.4 Ma	340	Karst network in open environment seasonal wetland	Flint pebbles and cobbles	<5–7 Km	Berruti and Arzarello, (2020)
Atapuerca Sima del Elefante TE9	1.3 Ma	71	Cave	Chert, quartz, limestone	<2 Km	de Lombera-Hermida et al. (2015)
Atapuerca G. Dolina level TD6	0.9 Ma	999	Cave	Chert, limestone, quartzite, quartz, sandstone	<5 Km	Terradillos-Bernal and Rodríguez-Álvarez (2014)
Le Vallonnet	1.1–1.2 Ma	104	Cave	Limestone, sandstone, quartzite, flint, quartz cobbles	0–5 Km	Cauche (2021)
Pont-de-Lavaud	1.1 Ma	264 (unambiguous)	Open air, fluvial	Quartz pebbles and cobbles	*In-situ*	de Lombera-Hermida et al. (2016)
Vallparadís level 10	~1 Ma	10,613	Open-air, fluvial-marshy, alluvial/colluvial conglomerates	Quartz, flint, lyddite, quartzite, limestone, sandstone, hornfel, jasper pebbles and cobbles	0–5 Km	García et al. (2013)
Bois-de-Riquet (US2)	1–0.9 Ma	23	Basalt flowstone cavity	Basalt (encasing)	0–5 Km	Bourguignon et al. (2016)
Ca' Belvedere di Montepoggiolo	0.9 Ma	520	River delta	Flint cobbles	0–5 Km	Arzarello and Peretto (2017)
Happisburgh 3	0.99–0.78 Ma	78	Open-air: flood plain, salt marsh	Flint	-	Parfitt et al. (2010)
Bizat Ruhama	1.6–1.3 Ma	1,958	Coastal, interdune depression	Chert pebbles	<1 Km	Zaidner (2013)

Sima del Elefante TE9 and Gran Dolina TD6, le Vallonnet, Vallparadís). The flint-limestone dichotomy is a defining feature found only in the Orce sites, where these two rock types are characterized distinct operative schemes. Hominin adaptation to the materials offered by each territorial context is further highlighted by rock type variability (esp. at Vallparadís) and the use of basalt (BDR-US2) and quartz (Pont-de-Lavaud).

All of this underpins flexibility in European Oldowan hominin behaviors that shows analogous technological patterns over a period of some 1 million years: 1) selection of lithic raw material resources linked to the occupied environments (immediate vicinity: Peretto et al., 1998; Despriée et al., 2006; Barsky et al., 2010; Bourguinon et al., 2016; Titton et al., 2021; outcrops located between 1 and 7 km: Carbonell and Rodríguez, 1994; Arzarello and Peretto, 2010; García et al., 2013); 2) use of hard hammer direct percussion (Carbonell et al., 2008; Arzarello et al., 2016.) and bipolar-on-anvil methods (Peretto et al., 1998; García et al., 2013; Barsky et al., 2015a; de Lombera-Hermida et al., 2016; Mosquera et al., 2018; Titton et al., 2021); 3) stone reduction strategies dominated by unifacial techniques with unipolar, bipolar or orthogonally directed removals and, more rarely, multipolar and centripetal core forms (Desprée et al., 2006; Cauche, 2009; Arzarello and Peretto, 2010; Arzarello et al., 2012; García et al., 2013; Titton et al., 2021); 4) toolkits characterized by the abundance of small flakes; 5) ubiquitous percussive activities attested by the presence of (poorly standardized) macro-sized tools (Barsky et al., 2015b; Barsky et al., 2018; Titton et al., 2018). New, holistic approaches to lithic analysis, like the one presented here, highlight a wide range of actions and behavioral variability within these Oldowan contexts, in spite of their substantial uniformity (Titton, 2021). This new methodological approach, here focused on how raw material variability played a role in shaping hominin behaviors, provides novel interpretations to more deeply explore the multiple facets of the European Oldowan, highlighting the significance of its subtle but significant nuances.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

DB research, data collection, surveys, text and figures elaboration and Fuente Nueva 3 excavations director; ST research, data collection, surveys, excavations and text and figures elaboration; RS-R research; AB raw materials identifications for lithic refitting and surveys; SG surveying, petrography and text elaboration; TS surveying and geology; AS-R Orce site technician, database responsible, text and figures elaboration; OO Orce geologist, text and figures elaboration; J-GS Barranco León excavations director, text correction; IT-M research; JMJ-A director of the OrceProject, research, text correction.

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