ence of a land bridge in this region across the Rifian seaway at 6.23 Ma, some 250 thousand years before the onset of the Messinian Salinity Crisis. This corridor developed after tectonics closed the Betic seaway at 6.3 Ma and during the intensification of the latest Miocene glaciation at 6.26 Ma when water circulation in the Mediterranean became very restricted.

Evolving caves used for hominid occupation

Staying in Spain, but moving north, the Duero Basin is sandwiched between the Cantabrian Mountains to the north and the Iberian Chain to the south. Within this otherwise Cenozoic basin is the Sierra de Atapuerca, a Mesozoic inlier. The limestones and dolomites of the Sierra de Atapuerca are divided by the Hoyada Valley into two areas, the southern one of which is known as San Vicente. It is here at San Vicente that extensive cave systems are developed, with a multi-level cave system with about 4.7 km of explored passages and about fifty sediment-filled cavities (Fig. 17). These caves have been designated a UNESCO World Heritage site, as they contain the earliest and most abundant evidence of humankind in Europe, including thirty skeletons assigned to *H. heidelbergensis* of Middle Pleistocene age.

To understand the human occupation of the caves, their geomorphological evolution needs to be understood, as this controlled how and when humans were able to access the cave systems. Recently, Ana Isabel Ortega Martínez and colleagues re-evaluated the geomorphological development of the caves (Ortega *et al.*, 2013, *Geomorphology*, v.196, pp.122–137). The cave systems are developed at three main levels, with the passages formed as a result of groundwater flow during periods of time when the position of the water table was very stable. Today these cave levels are some +88, +70 and +58 m above the Arlanzón River, and are largely composed of subhorizontal passages with a zig-zag horizontal pattern as a result of a structural influence on the joint sets and bedding planes along which the caves were developed. The caves can be related to the positions of river terraces, and the Upper and Middle levels are thought to have been formed in the Early Pleistocence with the lowermost level dating to the Early-Middle Pleistocene. Fluvial down-cutting led to a series of accessible dry caves whose entrances were used by hominids from about 1.22 Ma ago until the end of the Middle Pleistocene when the cave entrances filled with sediment, sealing inside what is now known to be the most important hominid-bearing deposit in Europe.

Fig. 17. The Sierra de Atapuerca cave system developed as a series of horizontal passageways each formed at the position of the water table along with connecting shafts. Human occupation from 1.22 Ma ago led to the formation of Europe's most important hominid-bearing deposits. (Image courtesy of Ana Isabel Ortega Martínez, Centro Nacional de Investigación sobre Evolución Humana.)

Disappearing pseudotachylytes

Pseudotachylites are fault rocks that have undergone frictional melting as a result of slip at seismic rates. They are the most widely accepted and frequently used indicator of earthquake slip in an exhumed fault rock. However, reports of pseudotachylytes are rare when compared with the frequency and distribution of earthquakes in active faults. Is this because melting only occurs under exceptional circumstances or are pseudotachylytes under-reported from the ancient rock record? To answer this question James Kirkpatrick and Christie Rowe have examined the processes that might cause pseudotachylytes to be destroyed (Kirkpatrick & Rowe, 2013, *Journal of Structural Geology*, v.52, pp.183–198). Kirkpatrick and Rowe summarize the established criteria for identifying pseudotachylytes based on both field and laboratory observations, allowing an overview of the primary characteristics of pristine solidified frictional melts. Diagnostic criteria

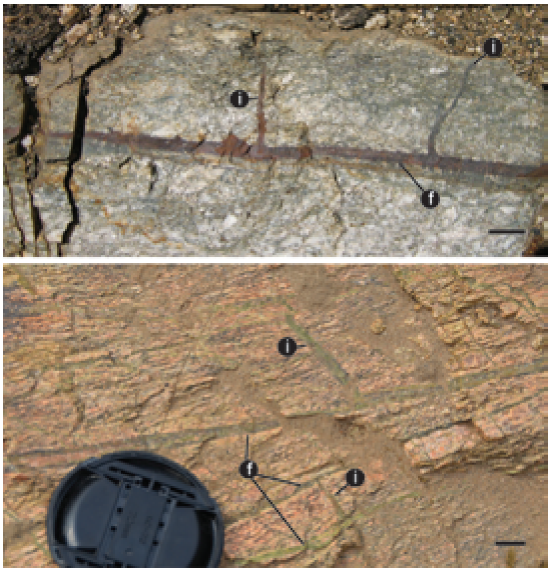

Fig. 18. Pristine and altered pseudotachylytes. Top: Dark brown-grey pseudotachylyte with characteristic geometry fault vein (f) and injection veins (i) branching from the fault vein at high angles. The groundmass in these veins is composed of textures that form during rapid quenching from a melt phase. Santa Rosa Mountains, California, USA. Below: Green pseudotachylyte veins showing the same geometry. The veins are green because the groundmass is replaced by epidote, destroying many of the primary textures diagnostic of the material having formed by frictional melting. Pofadder shear zone, South Africa. Scale bars in both images = 1 cm. (Image courtesy of James Kirkpatrick, Colorado State University.)

Fig. 19. Dinosaur tracks in the lake margin sediments of the Sousa Formation. After the tracks formed the surface dried out and superb mud cracks formed. (Image courtesy of Ismar Carvalho, Universidade Federal do Rio de Janeiro.)

include: quenched margins, euhedral microcrystallite grains (possibly with a dendritic habit or spherulites), sulphide/oxide droplets dispersed in the matrix, anomalously high temperature minerals, vesicles or amygdales and embayed edges and partial melting of clasts. At outcrop, melt-origin pseudotachylytes frequently form fault veins which are sub-parallel to the overall fault orientation, from which centimetre to tens of centimetre scale injection veins branch at angles of 70° or more (Fig. 18). Lenses, breccias and pockets that might host substantial amounts of melt material are also characteristic features which can be seen at outcrop.

However, the features which are characteristic of pseudotachylytes also help explain why they might be more vulnerable to alteration that the surrounding rocks (Fig. 18). Because they are often composed of very high temperature metastable glass and are extremely fine grained they are easily altered. They are also weaker than the surrounding wall rock and favour localized ductile flow and because of the mechanical contrasts may slip during fault reactivation. The originally complex geometries can be fractured and reworked during any subsequent deformation. Finally as faults are often pathways for pore fluids, alteration of the metastable minerals is highly likely. Consequently, pseudotachylytes are vastly under reported due to their vulnerability to destruction and the resultant difficulty in their identification. As a result of this the importance of frictional melting during earthquake slip is also under-reported.

Microbial mats preserve dinosaur footprints

Dinosaur footprints occur in at least 37 localities throughout the Lower Cretaceous Sousa Formation of northeast Brazil. Why are so many tracks preserved within these shallow warm temporary lake, swamp and meandering river sediments? Ismar Carvalho and colleagues think that the answer is because of microbial mats (Carvalho *et al.*, 2013, *Cretaceous Research*, v.44, pp.112–121). The Sousa Formation is composed of red mudstones, siltstones and fine grained sand-

Fig. 20. Reconstruction of the lake margin sediments of the Sousa Formation, Brazil in the Early Cretaceous, where the formation of biofilms allowed the preservation of dinosaur footprints. (Image courtesy of Ismar Carvalho, Universidade Federal do Rio de Janeiro.)