Analysis of Burnt Schist Outcrops in the Alps: Relation to Historical Archaeology and Hannibal's Crossing in 218 B.C.

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Identification of the exact route followed by Hannibal during his invasion of Italia in the Second Punic War is one of the major questions of antiquity and one that historians/archaeologists have long studied. One of the many clues in the ancient literature that can help answer this question is the mention of fired rock, the result of a conflagration Hannibal is reputed to have employed to reduce the size of boulders in a blocking rockslide some distance down from the high col on the Italian side. The only route with evidence of fired rock along the roadway leading into Italia follows the Col du Clapier, one of the possible northern routes discussed by historians. Radiocarbon dating of calcined rocks is not possible, but whereas Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS), Field Emission Scanning Electron Microscope (FESEM-EDS), backscatter electron scanning microscopy (BSE), High Resolution Transmission Electron Microscope (HRTEM), and Raman Spectroscopic data do not provide an age for the burnt rock, compositional evidence of the conflagration derived from these analyses may shed light on Hannibal's actual route. © 2007 Wiley Periodicals, Inc.

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INTRODUCTION

The routes Hannibal may have followed (Figure 1) on his historic invasion of Italia in 218 B.C. have been debated for centuries by legions of historians (e.g., Dodge, 1889,1891; de Montholon, 1905; Lamb, 1958; Hart, 1967; de Beer, 1956, 1967, 1969a, 1969b; Dupuy, 1969; Dupuy et al., 1992; Lazenby, 1978; Caven, 1980; Bath, 1981; Bradford, 1981; Connolly, 1981; Cottrell, 1992; Peddie, 1997; Prevas, 1998; Bagnall, 1999; Baker, 1999; Lancel, 1999, amongst others), relying principally on the works of Polybius (1979) and Livy (1965). Other ancient historians (Strabo, 1999; Silius Italicus, 1996) provided slightly different interpretations, but essentially there are three approach routes and six passes Hannibal might have used to gain entrance into Italia (Mahaney et al., 2007). Knowledge of the exact route looms as one of antiquity's major questions, mainly because it would demarcate the area where geoarchaeological investigations might be initiated with some prospect of recovering artifacts of interest to historical archaeologists. Of all the ancient commentators, Polybius (1979) is the preferred source because he was a cavalry general in the Achaean

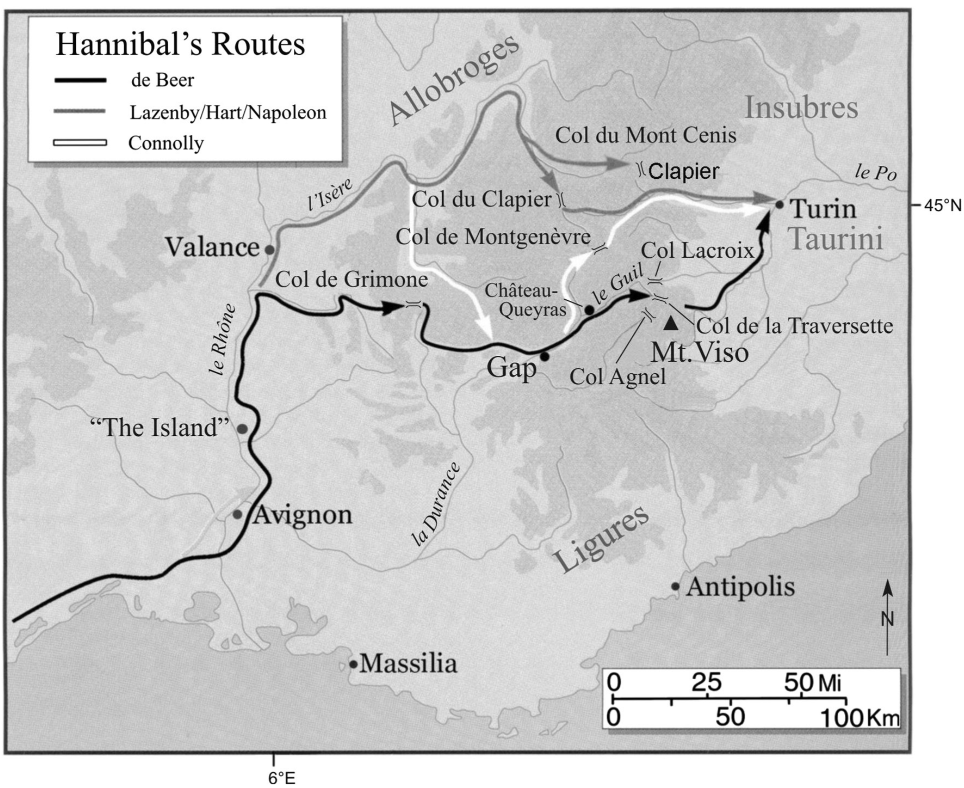

Figure 1. Three possible invasion routes followed by the Punic army during the Second Punic war leading to six possible cols. Base map adapted from Healy (1994). Approximate location of tribes (e.g., Ligures) shown in their approximate regional areas, although they ranged far and wide.

League, author of a major treatise on tactics (lost in the great fire at Alexandria, A.D. 300), and most importantly a historian who interviewed survivors of the great trek. Polybius retraced Hannibal's path some 60 years after the invasion (Lancel, 1999; Mahaney, 2004, 2007; Mahaney et al., 2007), basing his account on actual reconnaissance in the field.

Polybius consulted officers and enlisted men who had traveled with Hannibal in 218 B.C., and it is likely that he carried a copy of the original invasion log, commissioned by Hannibal and written by Silenus as a day-to-day account of what transpired between April and December of that year. Livy, on the other hand, writing over a hundred years after Polybius, never visited the invasion route through the Pyrénées and the Alps preferring instead to rely on Polybius and other historians in assembling his great history of Rome. Hence, many more recent workers, Lazenby (1978) and Lancel (1999) among them, consider Polybius to be the more reliable of the two ancient chroniclers of the Second Punic War.

The major difficulties in reconstructing the invasion route involve time and motion analyses, minor archaeological discoveries in the Pyrénées, matching of contemporary catchment names with names in the ancient literature (Walbank, 1990), and some measure of the topography of the approach routes and alpine cols through which Hannibal is said to have marched. Despite the importance of geology in most military campaigns (Rose and Nathanail, 2000), only de Beer (1967, 1969a, 1969b), Prevas (1998), Lazenby (1978), Mahaney (2004, 2007), Mahaney and Tricart (2007), and Mahaney et al. (2007) have discussed a possible match of the geological/topographical record with the ancient literature to arrive at the most probable route used by Hannibal and his army.

Among the many topographical, geological, and archaeological criteria in the ancient literature, the presence of burnt rock on the Italian side of the Alps was, according to Livy (XXI, 36), the result of Hannibal's engineers setting fire to timber laced around blocking boulders in an effort to fracture them. Thus, a burned outcrop might provide tangible evidence of the actual invasion route. Although growing evidence exists that Hannibal used the Col de la Traversette some 60 km to the south of the northern passes (de Beer, 1967, 1969a, 1969b; Prevas, 1998; Mahaney, 2004, 2007; Mahaney et al., 2007), the only col with fired rock so far identified on the Italian side is the Col du Clapier, one of the major routes into the Dora Riparia in the vicinity of ancient Torino. A number of researchers, including Dion (1962), Huss (1985), and Meyer (1953), have argued that Hannibal used the Col du Clapier, although few have considered why Hannibal would have detoured over the Col du Clapier when the route over Col du Mont Cenis offered faster access to the lowlands. More recently, Lancel (1999), invoking unpublished research of a mountaineer doctor, Marc de Lavis-Traffort, argued for a route over the nearby Col de Savine Coche at a similar elevation to the Col du Clapier (2497 m above sea level [asl]).

Other than the presence of a fired outcrop adjacent to the roadway leading into Italia, there is little to recommend the Col du Clapier or Col de Savine Coche (Figure 2) as Hannibal's route. It lies to the south of the main route into the Dora Riparia through the Col du Mont Cenis and is situated some 460 meters higher in elevation. The validity of the fire story may be suspect; whereas Livy (1965) described

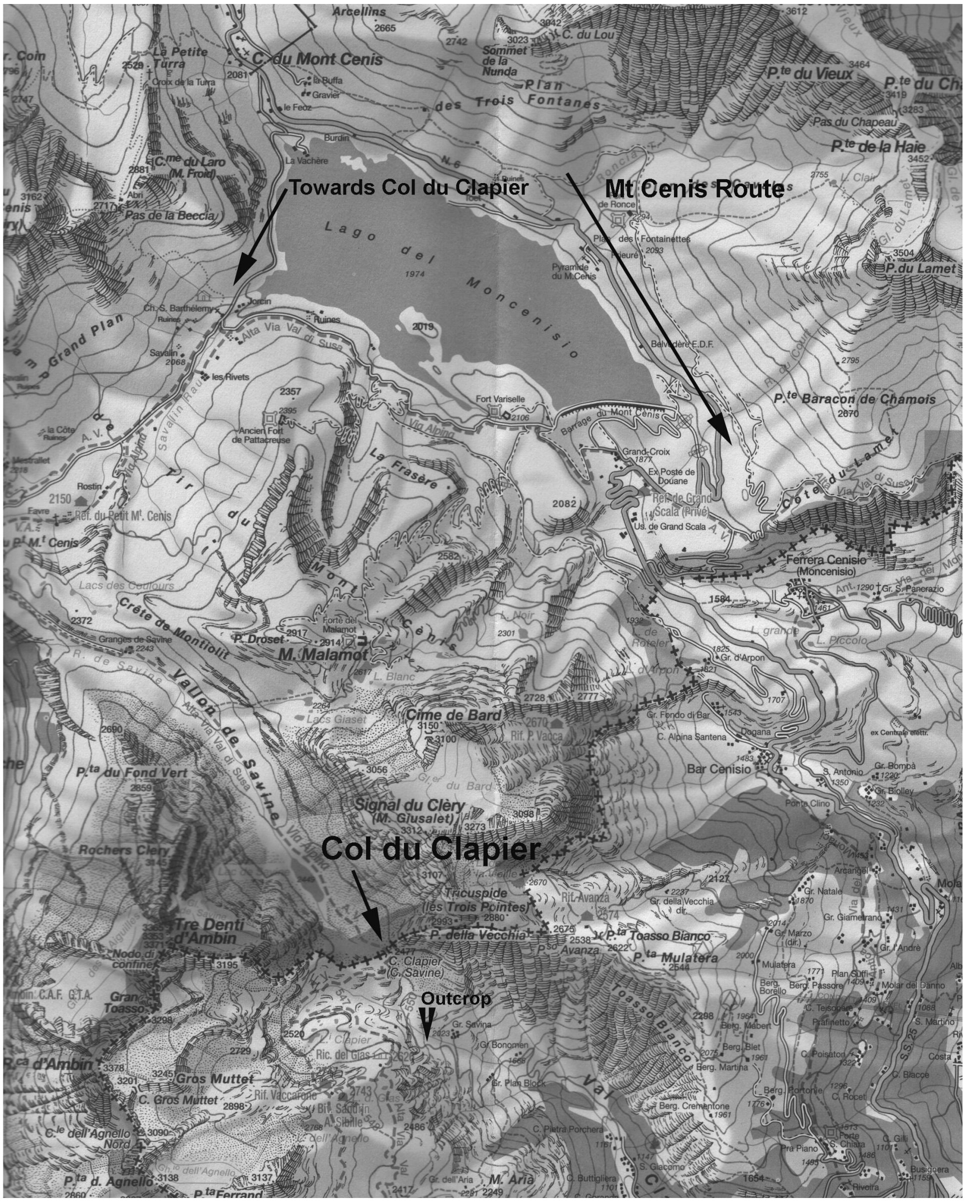

Figure 2. The Col du Clapier, along with the Col de Mont. Cenis is one of the northern cols Hannibal might have used to enter Italia. The Col du Clapier is the only entrance into Italia with burnt rock on the lee side, the fired rock correlating with descriptions in the ancient literature provided by Livy (from Mahaney et al., 2007).

the firing episode, Polybius (1979) is mute on the subject, despite describing the blocking "landslide" at length. Surely, Livy, who lived 160 years after the invasion and never traveled far from Padua, relied on second- and third-hand accounts of what actually happened when Hannibal and his starving army made their way over the alpine pass.

Despite numerous accounts of the Col du Clapier as a possible route, no researcher or historian has previously mentioned the presence of burnt outcrops below the col. The presence of fired rock begs the question as to whether it relates to Hannibal's crossing. With the chemical composition of the fired rock established, as outlined and discussed below, only the age of the burnt rock remains to be determined. Geoarchaeologists are left with the possibility that the fired outcrop may date to the 3rd century B.C. and to Hannibal's crossing. The intent here is to improve on previous work, to establish the chemical composition of burnt hornblende schist recently collected from the Col du Clapier, and to discuss the failure of accelerator mass spectrometry (AMS) radiocarbon dating to provide an absolute age of the fired crust.

The Problem

Trekking in the Hautes-Alpes, a copy of Polybius in one hand and of Livy in the other, one is left with few certain links between the ancient topographic descriptions and the present landscape (Mahaney, 2007; Mahaney et al., 2007). The situation has given rise to many questions and some startlingly different interpretations of the route Hannibal actually followed when he led his army from Cartagena in southern Spain between early May and mid-June, 218 B.C. (Figure 1). Moreover, Hannibal is thought by some authors not to have had any set route in mind (Connolly, 1981). Others with divergent opinions on the approach route and ultimate col have, by never visiting the field sites, created a certain myth about Hannibal's trek into Italia (Jourdain-Annequin, 1999), thus clouding the issue. However, once entering southern Gaul, Hannibal is believed by most authorities to have followed the Rhône River Valley northward, having his cavalry scout optimal local routes eastward through the Dauphiné and Hautes-Alpes. Any military officer who has led mountain operations would find the hypothesis of an unplanned or *ad hoc* route unbelievable, simply because lack of intelligence would risk entrapment, increase vulnerability, and lead to unacceptable delays, if not total pandemonium.

Although widely different troop numbers are quoted by different authorities (Polybius, 1979; Livy, 1965; Appian, 2002), it is most probable that Hannibal led an army of some 70,000 men (55,000 foot soldiers and 15,000 mounted on horses) plus an elephant corps of some 37 beasts north out of the Pyrénées, all requiring copious amounts of supplies. Hannibal had to have had adequate intelligence regarding his general line of march, as attested to by Polybius (III, 52, 53) and correctly interpreted by Proctor (1971). Certainly, Hannibal could plan deviations en route in the light of new intelligence gathered along the way, but his main line of march had to have been laid out well in advance, as deviations would have proven potentially destructive.

Beyond the Pyrénées, the three main routes proposed by most researchers who have studied the problem are shown in Figure 1. Of these three routes, most workers favor either the northern or southern variants. The third alternative involving a circuitous movement between the northern and southern routes likely would have led to critical delays and potential disaster. Taking the three routes as possible access vectors into the high passes, a number of factors must be considered, not the least of which include conflict with various Gallic tribes, river crossings, re-supply points, time of march with respect to harvest in northern Iberia and southern Gaul, time and motion relative to the approach of winter, topographic references in the ancient literature, surficial geology of the approaches and lee flanks of the Alps, presence or absence of firnpack (dense snow) on individual cols, and the presence of fired rock (Mahaney et al., 2007). However, in order to identify the invasion approach route and col, it is necessary to establish the composition and age of the fired rock outcrop below the Col du Clapier, as this alone provides evidence that Hannibal might have used this northern gateway to Italia.

GEOLOGICAL OVERVIEW

The Alps (Figure 3) straddle the boundary between the European and African tectonic plates. These plates diverged during the Jurassic and start of the Cretaceous, resulting in continental rifting followed by ocean birth and limited seafloor spreading. During the Cretaceous, the two plates began to converge, resulting in the subduction of the oceanic part of the plate(s) followed by general thrusting of the African margin

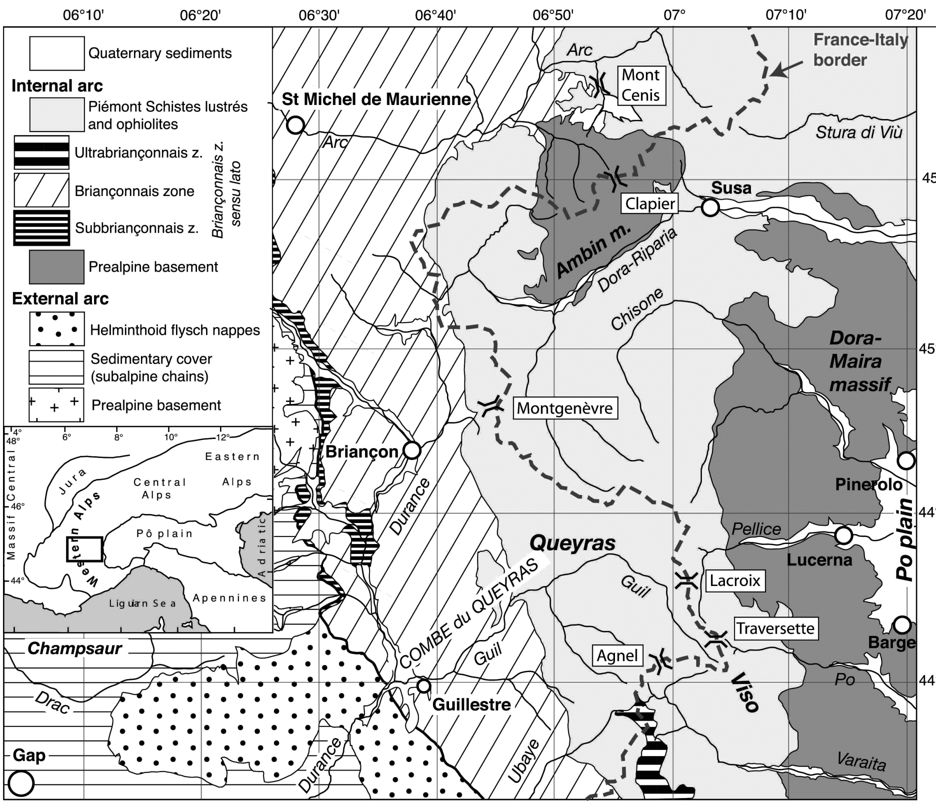

Figure 3. General geology of the Hautes-Alpes showing the location of major cols most researchers believe Hannibal may have transited with his army during the invasion of Italia in 218 B.C. (from Mahaney and Tricart, 2007).

onto the European margin. Continental collision developed throughout the Tertiary and remains active today, resulting in the 1000 km-long mountain barrier that isolates the northern plains of Italy from the rest of Europe.

The Western Alps consist of a north–south trending mountainous arc turning around the western part of the Po River plain. Its main crest line corresponds to the water divide between the Rhône and Po catchments and nearly everywhere marks the modern France–Italy border. Between Switzerland to the north and the Mediterranean shore to the south, there is no pass with an elevation lower than 1800 m. The geological structure of the Western alpine arc mainly consists of a stack of thrust sheets originating from the vanished ocean and its European continental margin, emplaced toward the exterior of the arc. Only a few remnants remain of the overriding African margin that has been almost totally removed by erosion. The thrust sheet stack was partially involved in late backfolds and backthrusts directed toward the interior of the arc, which resulted in the present-day fanning geometry of the general structure.

In the outer arc, a gently shortened and nonmetamorphic fold-thrust belt involves the Meso-Cenozoic sedimentary cover, more or less detached from its Prealpine (Hercynian and older) crystalline basement (Figure 3). The inner arc displays a much more complex structure. Highly imbricated nappes bear witness to intense ductile deformation and high-grade metamorphism (blueschist or eclogite facies). Gneissic nappes derived from the Prealpine basement dominate in the so-called "internal crystalline massifs" (e.g., Dora-Maira or Ambin massifs). In the Briançonnais (*sensu lato*) tectonic zone, nappes with carbonate-rich series originate from the upraised shoulder of the Lower–Middle Jurassic continental rift and from the steep slope of the Late Jurassic–Cretaceous passive margin. In the adjacent Piémont zone, a microbreccia-rich series associated with the boudined remnants of a thick Triassic dolomitic pile derived from the deep continental rift and from the distal part of the subsequent passive margin. Nevertheless, the Piémont zone mainly displays an ophiolite-bearing, calcschist-rich series (the so-called "Schistes lustrés"), originating from the oceanic realm.

In the central part of the Western alpine arc (Figure 3), which is of primary concern here, the main crest line lies essentially in the Piémont zone. The Ambin Massif (Col du Clapier) consists of Prealpine gneisses and micaschists. Elsewhere the Schistes Lustrés series dominates: upper Arc Valley (Col du Mont Cenis), Montgenèvre Massif (Col de Genèvre, now called Col de Montgenèvre) and the Queyras massifs (Col Lacroix, Col Agnel). Near the eastern tip of the Queyras, the Col de la Traversette is seated on a thick unit of metabasalts, a tectonic sliver within the Schistes lustrés pile.

MATERIALS AND METHODS

Chips of fired rock from outcrops at 1693 masl (GPS coordinates 45° 09' 28"N; 06° 56' 15"E; 804 m below the Col du Clapier at 2497 masl) (Figures 2 and 3) were collected in the field and returned to Toronto. These were initially examined with the light microscope and later by high resolution Field Emission Scanning Electron Microscope (FESEM), Energy Dispersive Spectrometer (LINK-ISIS), and Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS). Raman Spectroscopic Analysis was carried out at École Normal Supérior, Lyon, France.

A selection of chips, mounted in epoxy, were cut, polished, and examined, first with the light microscope and later with FESEM-EDS following methods outlined by Mahaney (2002). SEM imagery was collected on both the fired and fresh rock along with chemical spectra. Individual chips of fresh and fired rock were analyzed by ToF-SIMS, according to methods outlined by Sodhi et al. (2006). Briefly, the ToF-SIMS spectra were obtained on an ION-TOF TOFSIMS IV (ION-TOF Gmbh, Münster, Germany) located at the University of Toronto. A Ga-liquid metal ion gun was used and operated in a high spatial resolution-imaging mode (Sodhi, 2004). Prior to obtaining the images, the area was sputter cleaned using Ar ions. The fired and unfired rock chips were studied also by X-ray (XRD) and High Resolution Transmission Electron Microscope (HRTEM).

Raman Spectroscopy was used to study the graphitization of organic matter into carbonaceous-fired matter, a transformation previously studied in a variety of natural samples (Rietmeijer and Mackinnon, 1985; Pasteris and Wopenka, 1991; Beyssac et al., 2002). The method is based on the inelastic phenomenon of scattering of light by crystallized or amorphous materials after projecting a monochromatic light, laser beam source on the studied sample and analyzing the diffused light. The incidental photons are destroyed, and the energy used (1) creates diffused photons and (2) generates or destroys vibrations in the sample. The energies of vibration are characteristic of the material and crystalline structure. We used this approach in order to characterize the form taken by the graphite present in the patina of the fired schist. Moreover, we applied a thermometer based on surface ratios of the spectral bands of the carbonaceous material (Beyssac et al., 2002) to precisely measure the maximum temperature of heating responsible for the formation of the graphitized patina on the surface of the rock.

Laser Raman measurements of carbonaceous material were performed at the ENS-Lyon, France on a macroscopic sample of burnt schist A1, from Col de Clapier. We used a LABRAM HR800 double substractive spectrograph with premonochromator and a nitrogen-cooled SPECTRUM1 CCD detector. The premonochromator was equipped with confocal optics before the spectrometer entrance. The exitation was realized using a laser beam with a wavelength of 532 nm. A microscope was used to focus the exitation laser beam and to collect the Raman signal in the backscattered direction. A microscope with confocal optics was placed before the spectrometer entrance, allowing a sampling of about 1×3 μm sized analytical zone with a 50× objective and with a laser power of 700 μW at the sample surface. Acquisition time span was about 80 s distributed during five accumulating cycles. We focused on the 500 to 2500 cm^{-1} region in order to observe all first-order bands of the carbonaceous material. Baseline correction, peak position, and band width were determined by using the computer program Peakfit 3.0, based on the use of a Voigt function.

THE FIELD SITE

The steep (northeast facing) slopes below the Col du Clapier have no perennial snow or firnpack, but the drainages contain thick accumulations of snow to altitudes of ~1600 masl until mid-May. By early June the lowest limit of snow accumulation is at approximately 1750 m, just above the fired outcrop of hornblende schist. At approximately 1700 masl (804 m below the Col du Clapier), a 125 m long outcrop to the northwest of the road to the col shows evidence of fire at some undetermined time. The fired bedrock follows the roadcut laterally, stretching across a broad gully cut in bedrock with an irregular boundary angling upward about 30 m and downslope about 60 m. In all, the burnt area forms a rather irregular elliptical area of blackened/hematized rock surfaces, as shown in Figure 4A–C.

The site is located in the upper timberline area, where at present the diameter-breast-height of timber (primarily birch saplings) is small and biomass insufficient to fuel a conflagration such as described in the ancient literature. If Hannibal did use the Col du Clapier as an entrance to Italia, and assuming he required great quantities of timber, he would have had to transport dry wood to this site from below, along a distance of approximately 1.5–2.0 km. He would then have had his soldiers interlace boulders with dead wood and fire it to a temperature high enough to achieve rock spalling. Other agencies that could have caused the conflagration include forest fires started naturally during dry periods, perhaps by lightning (Barnett, 1911; Blackwelder, 1927; Grapes, 2006) or during road maintenance by a work crew. Other roads and tracks in Italy that have infrequent traffic are occasionally fired to remove vegetation and to maintain the right-of-way. The study area has been subject to transhumance for some centuries at least; hence the timberline may have been higher in the past, with sufficient dead wood at the site to fuel a fire started naturally or otherwise. In any case, the fire would have raised the temperature to several hundred degrees centigrade and produced a steep thermal gradient that presumably would have promoted rock disintegration (Allison and Bristow, 1999). The questions are to what extent the firing event changed the composition of the country rock and when the event occured.

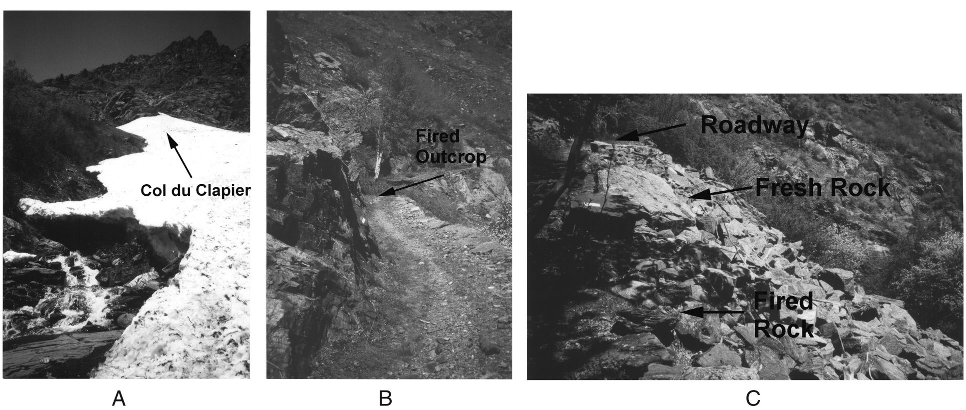

Figure 4. (A) View along the roadway leading down out of the Col du Clapier, showing the upper limit of birch in the ecotone between the alpine fell field and the lower subalpine forest; (B) Close-up of the fired outcrop; and (C) Rock rubble comprising a remnant of a former rockfall/slide with a narrow roadway.

RESULTS

Fired Patina

Clay minerals together with carbon compounds are identified in the fired rock patina, with various forms that relate to weathering and geochemical mobilization of surface rock minerals, mixed with aeolian-influxed materials and minor biogenic forms (mainly fungal filaments). This differs from previous work on primary carbon deposition from anthropogenic firings and raises the possibility of long-term preservation of the effects of fire on rock. The carbon veins in the fired rock are chemical in nature rather than the result of biogenic processes.

Radiocarbon Dating

Close visual inspection of the rock samples failed to show any charcoal fragments large enough for radiocarbon dating. Charcoal fragments likely would have been washed from the site a long time in the past. Several kilograms of rock were crushed and pretreated using a modification of the hot acid/alkali (AAA) extraction method, intended for removal of infiltrated humic contaminants (Mook and Streurman, 1983). Initially, the crushed rock sample was treated with hot 4N HCl for 24 hours to remove Ca salts and any acid-soluble humic contaminants. The residue was then demineralized in a mixture of hot and strong HCl and HF to reduce the bulk of the crushed rock sample to a more manageable size. The HCl/HF mixture was refreshed three times in the course of 1 week. The reduced rock sample was then treated with 0.25N NaOH for 1 hour to remove any alkali-soluble humic contaminants, followed by a thorough wash with 2N HCl. Throughout this pretreatment process, the residues were separated from their supernatants using a 25,000 g ultra centrifuge. The final residue was lyophilized and combusted. Two attempts to combust the dried residue produced less than 100 μgram of datable C in the form of CO_2, insufficient for a reliable radiocarbon analysis. The AAA/HF pretreatment method, described above, can extract most of the elemental carbon and charcoal and at most 50% of any wood products from a sample (Mook and Streurman, 1983), but will remove most other carbonaceous compounds, including carboxyl compounds from soot or hexane residues from gasoline.

Time-of-Flight Secondary Ion Mass Spectrometry

The chemistry of the burnt versus fresh hornblende was analyzed by ToF-SIMS to determine differences in positive and negative ion composition. The data in Figure 5 show positive and negative ion images obtained from the same area as the SEM image shown in Figure 6A. In addition to the elements normally associated with the hornblende schist and quartz-feldspathic minerals, other elements are present in the crust as well as within fissures. Of particular note is the distribution of elements that would arise from any wood-ash residue present after firing. Transport of weathered

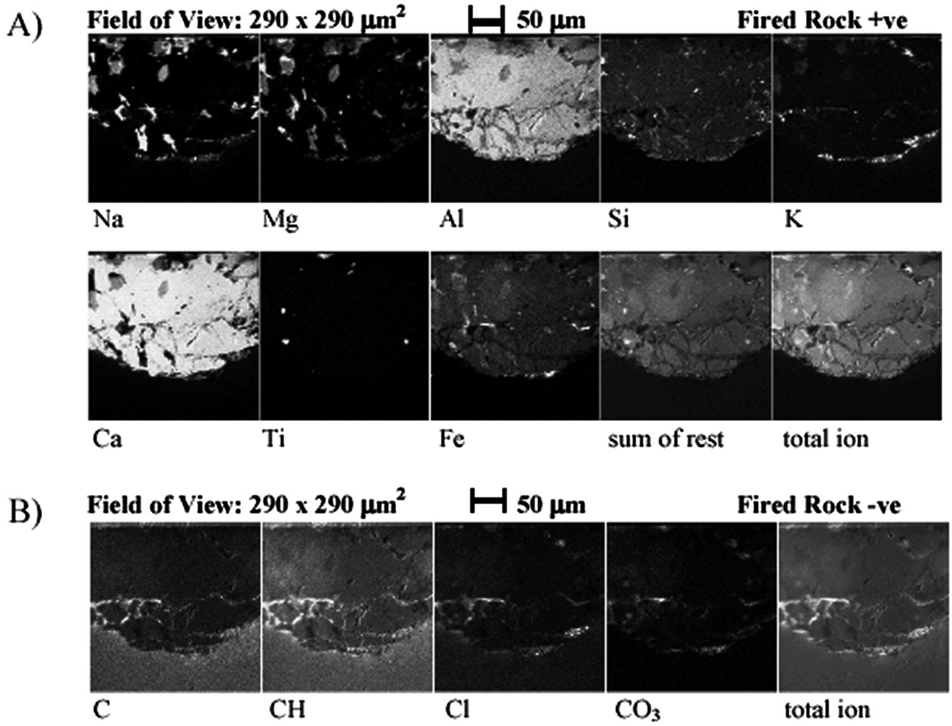

Figure 5. ToF-SIMS images of fired rock. (A) Positive spectrum; (B) Negative spectrum (from Sodhi et al., 2006).

products and geochemical mobilization of such elements should be indicated by their presence within cracks and fissures. Specifically, it is postulated that the presence and distribution of K in the burnt crust and within the fissures, as well as other fragments such as CO_3, provide a clear indication of wood ash resulting from the burning of timber. Use of other combustibles, such as gasoline, would not leave such a residue, nor would nonhuman-induced firing of sparse bush caused by a lightning strike.

Support for the above hypothesis comes from ToF-SIMS imagery of a non-fired crust (Sodhi et al., 2006), where little or no K is seen either at the surface or within cracks or fissures. Little or no C species were identified in the positive spectra (not shown), which is not too surprising, because most carbonaceous material would be destroyed. However, the carbon species must have a low positive secondary ion yield, because C species are clearly observed in the negative ion image and are concentrated within the vein structure. Although much of the Na is associated with Mg, nonassociated Na can be seen both at the fired crust and within the fissures, an indication of the geochemical mobilization of the surface rock elements. This is also observed with other elements that would be expected to be mobile, such as Cl. Other fragments were also observed within the fissures, such as

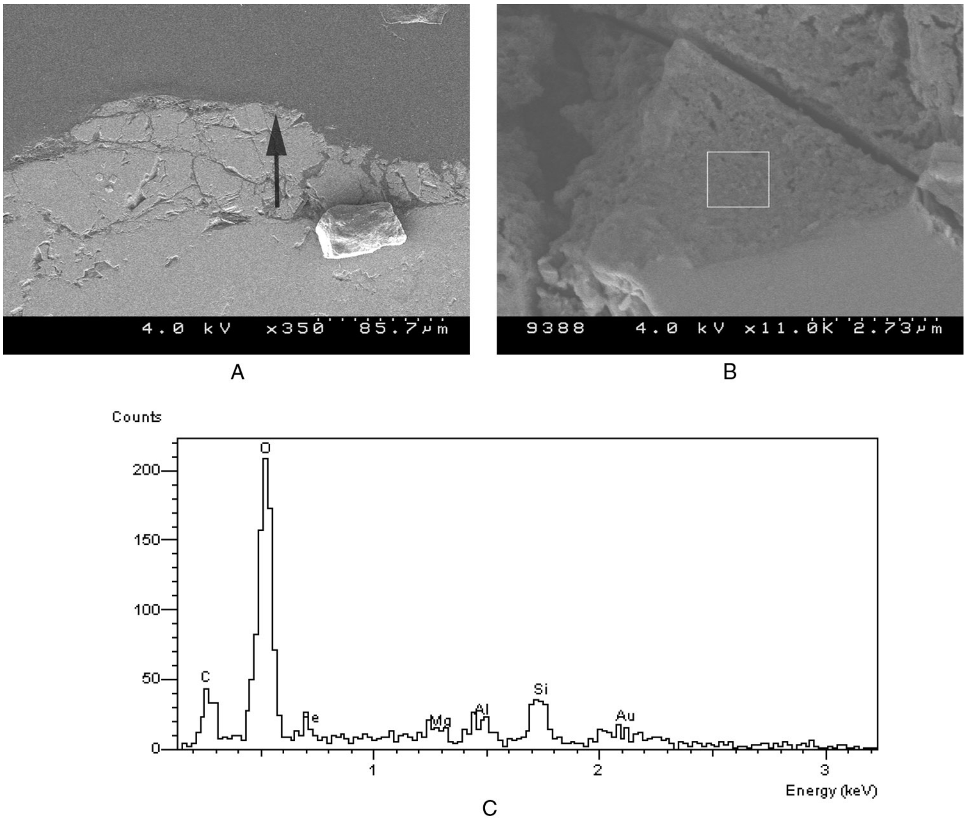

Figure 6. (A) Low magnification image of the burnt rock showing carbonized crust (arrow) and breccia zone resulting from the conflagration; (B) SEM enlarged image of the fired rock showing microbreccia and fracture zones induced by firing; (C) Chemistry of the rectangle in the fired rock image of B.

CO_3 and possibly S. Some mobilization of Cl and the presence of carbon-containing species is observed in the non-fired rock, though to a lesser degree than in the fired example.

Scanning Electron Microscopy and Energy Dispersive Spectrometry

Burnt and fresh rock samples were investigated with SEM-EDS (scanning electron microscopy energy-dispersive spectrometry) to characterize the fresh versus burnt rock. As shown in Figure 6A, the burnt crust is clearly visible as a carbonized rim between the epoxy (upper area) and the fractured (breccia) zone, which evidently ruptured but suffered only minor carbonization. Additional brecciated and slightly carbonized samples were imaged to produce higher magnification analysis (10–11 k) of the fractured crust. Figure 6B shows slight variations in fracture propagation and thickness of the carbonized crust. The chemical spectrum of the area outlined in

Figure 6B is shown in Figure 6C and evinces a small amount of C from the conflagration. The small amounts of Si, Al, Mg, and Fe probably result from volatilized elements of the rock itself, incorporated into the carbonized crust. The presence of Au in the sample is from the light sputter coating. The high oxygen in both samples probably represents carboxyls or other hydrocarbons resulting from the conflagration.

Backscattered Electron Data

Seeing thin black crusts (patinas) on rocks, the first inclination is to suspect the presence of manganiferous rock varnish (Dorn, 1998). Such coatings do exist in a few of the rock crusts examined (Figure 7A). Wavelength dispersive electron microprobe (WDS) analyses of this varnish, with a defocused 10 μm spot, yields a typical composition of: Na_2O = 0.11%, MgO = 2.44%, Al_2O_3 = 12.30%, SiO_2 = 23.41%, P_2O_5 = 1.45%, SO_3 = 0.09%, K_2O = 1.27%, CaO = 0.80%, TiO_2 = 0.67%, MnO = 17.25%, FeO = 16.83%, BaO = 0.23% (the total is well below 100% because of the high sample porosity and other elements present). The significance of the rock varnish rests in a clear differentiation between the sorts of typical rock coatings found naturally and the burnt crust studied here.

In contrast to the manganiferous rock varnish, the burnt crust had a much lower brightness when imaged with backscattered electrons. To see the burnt crust clearly with BSE imagery, the contrast had to be reduced. The material appeared to have a layered structure (Figure 7B), perhaps imposed by the clay minerals present. The grayscale variations in the BSE image (Figure 7B) derive from the dark black void spaces and from carbon-rich areas (due to the low Z of carbon). The overall mottled effect probably derives from a mixture of carbon with silicates (Figure 7B).

High-Resolution Transmission Electron Microscopy

High-resolution transmission electron microscopy reveals subtle variations in the texture of the burnt crust. We concentrated on one particular location that showed a clear demarcation between carbon-rich and alumno-silicate-rich zones in Figure 7B. Figure 7C shows two examples with thin-enough crusts to image both the carbon-rich and clay-rich zones. A fairly distinct boundary appears to separate the granular carbon-rich "burnt" material and the layered clay minerals (Figure 7C); however, there appears to be a zone of transition where the granular texture interleaves with the layered clay texture.

Magnetic Investigations

Preliminary investigations of a few unoriented block samples collected from the outcrop reveal soft magnetization typical of lightning-affected rocks, and high Koenigsberger ratios (Cox, 1961; Dunlop et al., 1984; Verrier and Rochette, 2002; Maki, 2005) that suggest the possibility of lightning impact. The Koenigsberger ratio is the ratio of remanent magnetization to magnetization induced in the sample by

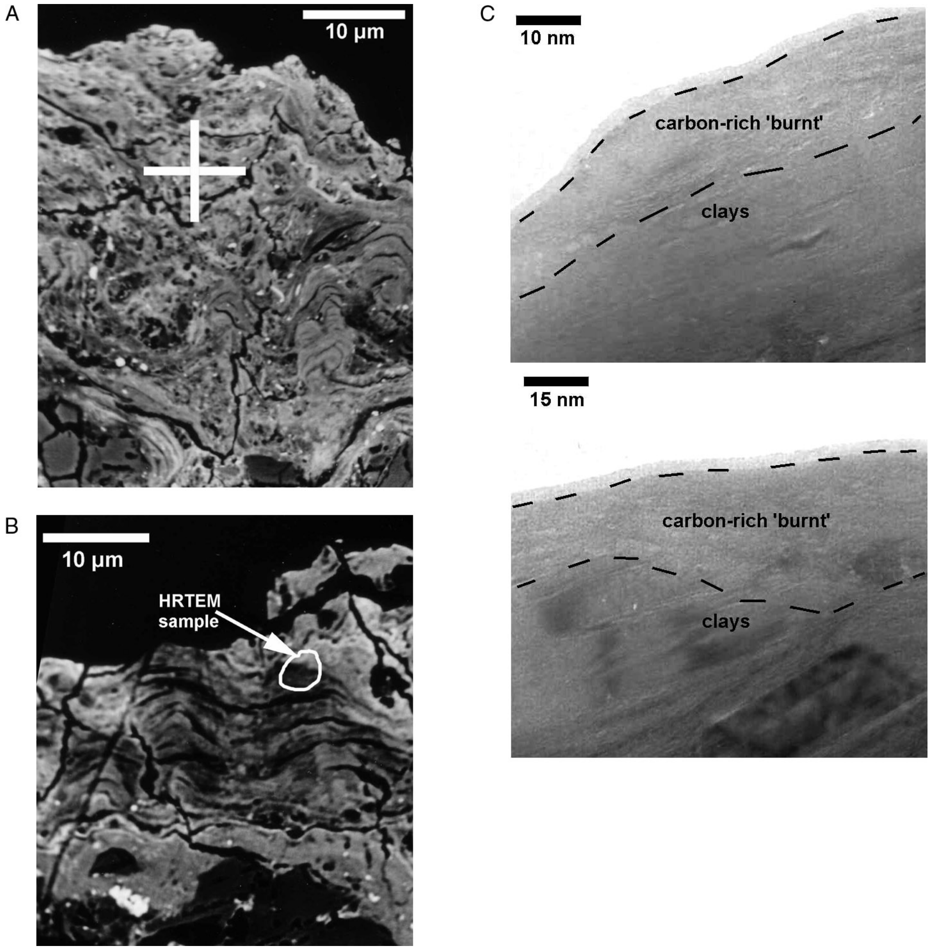

Figure 7. (A) Rock varnish from a fissure near the burnt crust. The cross indicates the location of the WDS electron microprobe analysis with a 10 µm defocused beam. The highly porous nature of the varnish reflects the moist conditions at the site promoting leaching of cations from the varnish structure; (B) Backscattered electron microscope image of an area of burned crust. The high-resolution transmission electron microscope (HRTEM) images come from the area indicated by the arrow. Wavelength dispersive scans revealed peaks in carbon in these dark, mottled areas. In contrast, EDS analyses showed higher presence of Al and Si in the brighter areas in the image. The very brightest region are areas of Fe, perhaps iron oxyhydroxide precipitation, as revealed by point EDS analyses; (C) High resolution transmission electron microscope images showing the boundary between clays and carbon-rich zones in the burnt crust. The approximate location of these images comes from the arrow indicated in Figure 7B. Clay minerals have a layered texture in both frames. The carbon-rich zone, as revealed by WDS analyses, has a more granular texture at the nanometer scale. The outermost amorphous zone is an artifact of beam effects.

the earth's magnetic field. More work is required before a solid case can be made that the rocks of Col de Clapier were lightning affected. Rock promontories at these latitudes (Barnett, 1911; Grapes, 2006) are very often affected by lightning, so it would not be unexpected at this particular location.

Raman Spectra

Graphitization, that is the solid-state transformation of organic matter into carbonaceous material, is a process that may be observed at the surface of fired rocks or in metamorphic rocks. The fired amphibolite schist of concern here was subjected to Raman Spectroscopic Analysis and locally distributed spectra of carbonaceous material were obtained. In the best case, we obtained spectra presenting two characteristic peaks in the first-order (1100–1800 cm^{-1}) area of the carbonaceous material (Figure 8, curve a). The deconvolved spectra shows five bands including four that are significant for the carbonaceous material (Figure 8, curve b). The band centred at 1603 cm^{-1} is interpreted as the graphite band (G band) and corresponds to the vibration mode of aromatic carbons in the graphitic structure (Beyssac et al., 2002). The well-developed band occurring at 1360 cm^{-1} is interpreted as the D1 band of the carbonaceous material. It is attributed to the presence of defects such as heteroatoms (O, H, N) or structural defects (Bény-Bassez and Rouzaud, 1985). The two other bands centred at 1485 and 1778 cm^{-1} correspond respectively to the D3 and D2 bands. They are attributed to out-plane defects, such as tetrahedral carbons early released during the graphitization process (Bény-Bassez and Rouzaud, 1985).

Temperature Estimates and Discussion

The Raman spectra of carbonaceous material provide a geothermometer of the maximal temperature conditions suffered by rocks in the range 330–650°C (Beyssac et al., 2002). This thermometer is based on an area ratio (R2) of different characteristic bands of the carbonaceous material ($R2 = D1/[G1+D1+D2]$). The correlation between R2 and the peak temperature is described by the following linear function: $T(°C) = -445R2 + 641$. In the case of the spectra of the burnt schist patina, the surface ratio R2 gives a temperature of 363 °C with an intrinsic error calibration of +/−50°C. This result must be considered with caution because Beyssac's method was developed to determine the peak temperature reached during

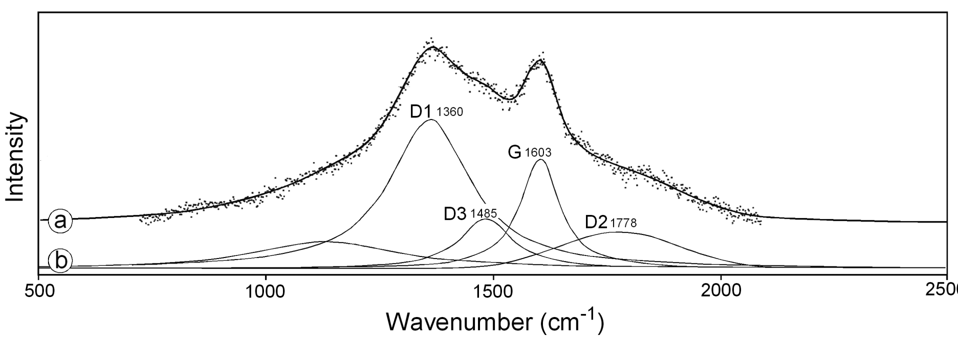

Figure 8. Raman spectra of carbonaceous material in the first-order region obtained on the graphitized patina of the burnt schist (sample A1). (a) Non-deconvolved spectra; (b) deconvolved spectra into four distinct characteristic bands of carbonaceous material.

regional metamorphism events. It implies slow transformations, especially when compared to the almost instantaneous heating suffered by the burnt schist from Col du Clapier.

No change in mineralogy was detected, either by light microscopy, SEM, or Raman Spectroscopy, because the heating suffered by the samples was instantaneous. The main parameters controlling the kinetics of mineralogical phase transition are the temperature (controlling the diffusion process) and the heating event duration. In Col du Clapier, for example, the firing temperature is insufficient and duration geologically negligible. The only detected phase transition concerns the organic matter fused on the samples.

DISCUSSION

The Col du Clapier is perhaps the least likely entry point into Italia. It is off the beaten path even today, and in Hannibal's time the col route would have been known only to local inhabitants as a deviation from the nearby Col du Mont Cenis route some 413 m lower in elevation. The Col du Clapier certainly is not one of the main routes mentioned by ancient writers, although a select number of historians consider it and the nearby Col de Savine (see Figure 2) as likely avenues for Hannibal's transit into Cisalpine Gaul. It certainly leads to the Dora Riparia through the Val Clarea and is on the direct route to lands previously inhabited by the Taurini Gauls. One proviso is that Polybius (III, 56) mentions Hannibal debouched upon the "plains of the Po River" which more accurately describes the topography to the south of the Dora Riparia, not the deep valley of the Dora Riparia itself.

The historian C. Terrentius Varro (in Proctor, 1971) labeled passes in the order to which they were known in the 1st century B.C. and placed Hannibal's pass south of the Col de Montgenèvre, which is well south of the Col du Clapier. The most likely candidate for "Hannibal's Pass" is the Col de la Traversette, matching de Beer's (1967, 1969a, 1969b) interpretation that Hannibal crossed over it into the upper Po River Valley. Indeed the Col de la Traversette is the only col with a two-tier (superposed) rockfall/slide complex at 2600 masl, matching the landform described by Polybius (III, 54) that blocked Hannibal's egress out of the col. Although Polybius described this mass as a "landslide," it is clearly a combination rockfall/slide complex, the most recent upper layer dating from the Late Holocene or within the time frame of the Punic Wars (Mahaney, 2007; Mahaney et al., 2007).

Notwithstanding the evidence against the Col du Clapier, the presence of fired rock on ledges below the col itself (the only approach route into Italia with burnt outcrops) begs the question as to whether it relates to Hannibal's time and to the event described by Livy and subsequent historians (cf., Bagnall, 1999; Baker, 1999; Lancel, 1999, to name a few) who have adopted Livy's description of events while studying the invasion. The blackened surface of the fired outcrop observed in the field indicated that AMS radiocarbon dating would likely provide an age for the conflagration, yet, as previously discussed, it proved impossible to recover sufficient carbon in the laboratory to yield an absolute age. Subsequent microscopic and chemical analyses provided important physical and compositional data that showed the firing event did not affect the mineralogy, a finding which indicates a low firing temperature confirmed by Raman Spectroscopy. Analysis by ToF-SIMS clearly showed a residue in the fired patina of K and CO_3 derived from the burning of timber, which may indicate the distribution of forest was more expansive than now.

The biggest question regarding the fired rock hypothesis outlined in the ancient literature is whether it actually occurred. Was it the by-product of an imaginative person, Hannibal's personal historiographer, for example (Lancel, 1999), who might have had as motive the desire to build his patron's reputation, or was it a conflagration caused by lightning, an unusual dry period, or human carelessness? What better way to portray Hannibal as an insightful and ingenious commander than to have him solve the riddle—how to bypass the blocking rockslide/fall his engineers could not remove—a major impediment to the successful descent of the Carthaginian Army as it evacuated from a high alpine col.

Although none of the other major passes into Italia have fired rock on the lee side, the presence of burnt hornblende schist below the Col du Clapier is the only criterion that marks the pass as the one Hannibal actually used. Yet the blackened schistosic boulders found at this location are hardly of a size (0.3–1.00 m) that would inhibit the movement of any army including horses, mules, elephants, and baggage train. Surely, Hannibal's engineers, using metal tools, could lever stones of this size out of the way without firing the outcrop. Substantial landforms or accumulations of rubble described as a massive "landslide" by Livy (XXI, 36) and "two-tiered landslide" by Polybius (III, 54) are missing below the Col du Clapier. Indeed, there is rubble below the Col du Clapier, but it is far lower in volume and smaller in clast size than that which exists below the Col de la Traversette. The permanent snow (firnpack) described by both Polybius and Livy as a major impediment to Hannibal's progress once he reached the crest of the Alps is also missing from the slopes below the Col du Clapier, but present on the higher Col de la Traversette, some 60 km to the south (Mahaney et al., 2007). From what is known of climate change over the last two millennia (Neumann, 1992), it is doubtful the Col du Clapier had firnpack present on its slopes during Hannibal's time. The fired rock is the only evidence suggesting that Hannibal may actually have used the Col du Clapier to gain entrance into Italia.

The only primary source to mention the firing event is Livy (XXI, 37), who describes in vivid detail that the Punic Army was stopped by a massive slide/fall of rock and the engineers were stumped as to how to remove or bypass it. Hannibal, summoned from the rear echelons, was reportedly quick to devise a method using timber as fuel to heat boulders to a high temperature and then dousing the flaming mass with sour wine to crack boulders to a manageable size, which then could be discarded. If the mass of material shown in Figure 4C stopped Hannibal, he could easily have cut a new route around the blocking rubble and continued down into the lower valley. Polybius (III, 55) is definite on this point, namely, that there was no other route off the mountain. The rockfall/slide had to be negotiated before total collapse set in among his troops.

CONCLUSIONS

The description of Hannibal firing rock rubble on the lee side of the Alps, a desperate attempt to comminute large boulders to a size manageable for removal by engineers is provided initially by Livy. Polybius is mute on the event, which, given the thorough treatment he provides on other day-to-day events during Hannibal's alpine transit, suggests it never happened. However, despite the fact that Livy never visited the alpine passes as Polybius did, he may have had a source unknown to Polybius that described the firing event.

The identification, made for the first time in 2004, of fired rock below the Col du Clapier (Sodhi et al., 2006; Mahaney et al., 2007) begs the question as to its age and origin. Although the age of the firing event eludes us, the composition of the burnt rock indicates it involved burning of timber caused either by lightning or human-induced ignition at some time in the past. Various lines of chemical analysis indicate the firing event consumed large quantities of forest and understory vegetation in a low temperature conflagration. The question remains open as to whether the firing episode is related to Hannibal and passage of his army into Italia or to some other natural or human-induced event. The fact that so much of the fired rock is hematized suggests the fire may well have been initiated by a lightning strike, although magnetic analysis is inconclusive on this aspect.

Despite the failure to date the carbonized crust by radiocarbon analysis, other components of the crust, including the ingress of clay minerals and fossil microorganisms, suggest the firing event has a certain antiquity. Just how much antiquity is the question. It is unknown how long it takes for fungi to colonize, grow, and die in the carbonized crust, eventually becoming entombed there as fossil forms. The fired outcrop is at the base of a 30-degree slope, across which the removal of weathered material is rapid enough to preclude the development of appreciable soil. Thus, soil development is not much of an aid in determining the age of the fired outcrop, and no discernible charcoal is preserved in surface litter. The road ballast upon which the pathway was constructed has been reinforced many times reaching far back into antiquity, possibly before the time of Hannibal. Thus, although we know the conflagration that led to the development of the carbonized crust was fueled by native wood, as indicated by the concentration of potash in the burnt layer, we do not know the age of the event.

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