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POLYBIUS' 'PREVIOUS LANDSLIDE': PROOF THAT HANNIBAL'S INVASION ROUTE CROSSED THE COL DE LA TRAVERSETTE

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ABSTRACT

Both Polybius and Livy described a landslide/landslip that blocked the Punic Army's exfiltration from a high col on the water divide in the Western Alps. The landslide, more aptly termed rockfall, has been a source of contention amongst classicists for centuries despite the fact that only two cols—Clapier and Traversette—exhibit rockfall debris on the lee side of the Alps. While the Clapier rockfall is too small and too young to have provided blockage, the Traversette debris is nearly as Polybius described it when he retraced the invasion route some 60 years after the event. His 'two-tier' description of the deposit, a doublet of younger and older rock rubble, including measurements of width and volume are close to modern measurements and prove that he knew, in advance, the route Hannibal had followed. It would take a practiced eye to correctly identify the stratigraphic complexity inherent in the Traversette Rockfall. Here we present weathering ratios, soil stratigraphic, mineral, chemical and microbiological evidence in support of Polybius' observations as a considerable background database for future geoarchaeological exploration.

KEYWORDS: Hannibalic invasion, Traversette Rockfall, Physico-mineral-chemical correlation to ancient texts.

1. INTRODUCTION

The landslide (cf. rockfall; Figs. 1A, 1B) described by Polybius and Livy (Polybius, trans Scott-Kilvert, 1979; Livy trans. de Sélincourt, 1972) as a major impediment to Hannibal successfully exfiltrating the high Alps during the invasion of 218 BC has been discussed by countless authorities (Dodge, 1891; Wilkinson, 1911; Proctor, 1971; Seibert, 1993; Renaud, 1996; Lazenby, 1998; Bagnall, 1999; Lancel, 1999; Connolly, 1981; Cottrell, 1992; Mahaney, 2004; Mahaney and Tricart, 2008; Mahaney et al., 2008) over the last two millennia. Few (de Beer, 1967, 1969; Prevas, 1998) have ventured forth in search of landslide/rockfall debris on the lee side of the Alps below any of the major cols and fewer still have made any attempt to identify the deposit described by Polybius (Mahaney, 2008; Mahaney et al., 2010a).

Of all the environmental targets that would help to identify the correct col of passage by the Punic Army, the search for and identification of a deposit similar to the one described by Polybius would bring to a close the longstanding question of the route Hannibal followed into Italia. The route question, long a source of contention among classicists (Mahaney et al., 2010b), is important more for targeting sites worth geoarchaeological excavation than to satisfy the musings of armchair theorists, as no artifacts or other geoarchaeological evidence of the invasion have ever been found. To confound the issue, even if artifacts or other evidence were to be found, it would be doubly difficult to pinpoint material originating from Hannibal's expedition, as his brother Hasdrubal crossed over into Italia with a large army some eleven years after the main Punic Invasion of 218 BC.

Despite the route controversy that has raged over the post-invasion period, recent critical comment of the Traversette Route (Kuhle and Kuhle, 2012) pinpointed the importance of establishing the stratigraphy of the two-tier rockfall (Fig. 2) described by Polybius some 60 years after the invasion. As pointed out by Mahaney (2012) the 'two-tier' nature of the rockfall mass, originally described by Polybius, is key to identifying the route and presumably a prime locality for geoarchaeological exploration and excavation. The two-tier nature of the rockfall is clearly evident in the field, the older mass of Late Glacial age lying astride the younger mass originating during the Neoglacial.

Polybius' description of the rockfall: 'A previous landslide had already carried away some 300 yards of the face of the mountain, while a recent one had made the situation still worse', (translation by Scott-Kilvert, 1979), sums up the two-tier mass faced by the Punic Army following their descent from the high pass. In Livy's words the rockfall is described thus (translation by de Sélincourt, 1972): 'Soon they (Punic Army) found themselves on the edge of a precipice—a narrow cliff falling away…a recent landslide had converted it on this occasion to a perpendicular drop of nearly a thousand feet.' Livy quotes other sources but never witnessed the mass wasted deposits at the site as Polybius did, the latter the prime authority on the invasion.

An important proof for the Late Glacial age of the older mass is the presence of cosmic impacted grains in rock rinds at the V9 site (Fig. 2) which have been correlated with the black mat event of 12.8 ka (Mahaney et al., 2013). The age of the younger debris sheet is based on soil profile characteristics that correlate closely with similar Neoglacial-age profiles near Mt. Blanc, ~60 km to the north (Mahaney, 1991). Because the Traversette Rockfall is the only lee-side composite rockfall of two deposits, one superposed on the other, it is clearly the mass identified by Polybius during his momentous reconstruction of the invasion carried out in the field.

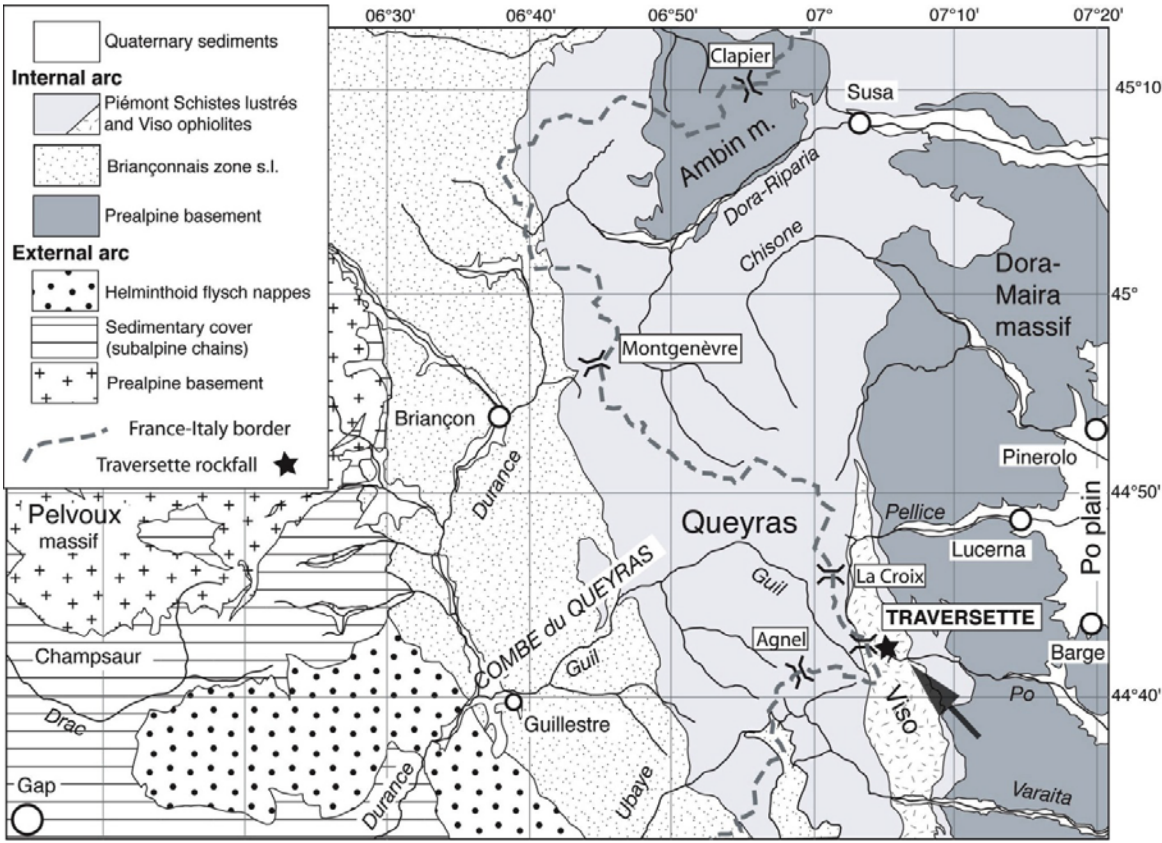

Figure 1A. Location of sites in the Traversette Rockfall and the Col du Clapier, Italian Alps. The map is from Mahaney et al., 2010.

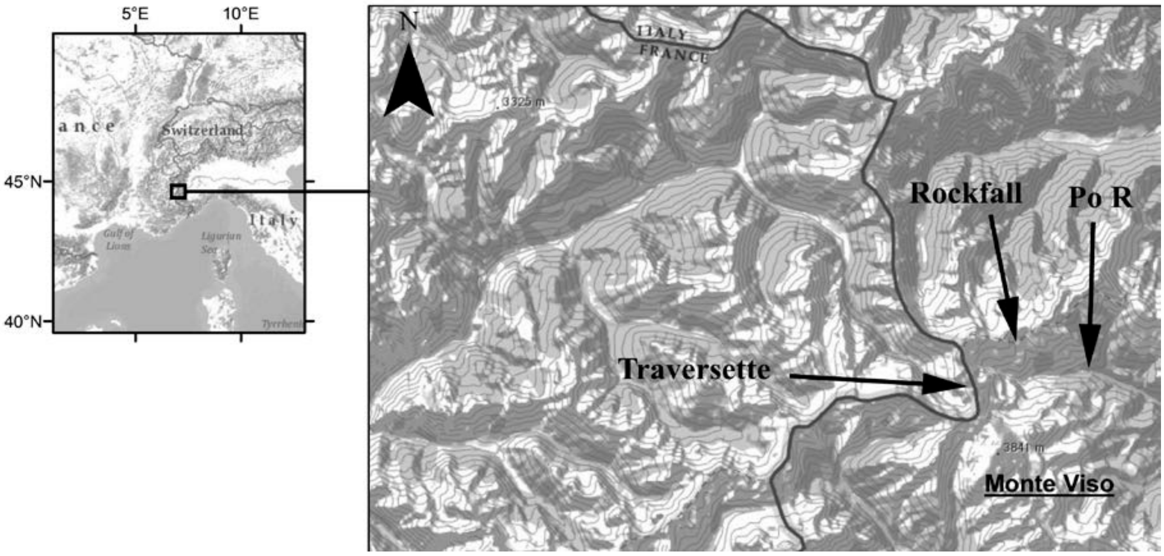

Figure 1B. Contour map and location of the Traversette Rockfall in the Mt. Viso area.

A search of all major passes, from what is now the boundary of France and Italy, are of variable height and most trails are steeper on the Italian side as a result of the tectonic structures that have emplaced thrust sheet upon thrust sheet (Mahaney, 2010a). All paths follow steep inclines into Italy, mostly over bedrock, talus and moraine with variable amounts/volumes of rockfall sediment. A search of these areas from south to north for suitable deposits similar to what Polybius described covers all possible routes. Livy, often considered the first modern historian, never left Padua rendering all his descriptions second-hand; whereas Polybius actually interviewed survivors (albeit some sixty years after the invasion when memories were dulled by the passage of time) and followed the invasion route across Iberia into southern Gaul (now France) and over the Alps into the headwaters of the Upper Po River (Mahaney, 2008). Polybius described the high alpine environment providing details of the 'landslide' that blocked the army creating an impediment to the passage of the elephant corps, soldiers, horses and mules. The infantry could pass, albeit with difficulty the rubble mass that lay across the slope, but the animals were spooked by the rubble. To find the rockfall that correlates in size and volume with what Polybius described is to find the route and to prove that Polybius actually visited the site. That is the substance of this report, the search for the great impediment that nearly upset the invasion schedule, finally identified conclusively by Polybius' description and the stratigraphic evidence reported here.

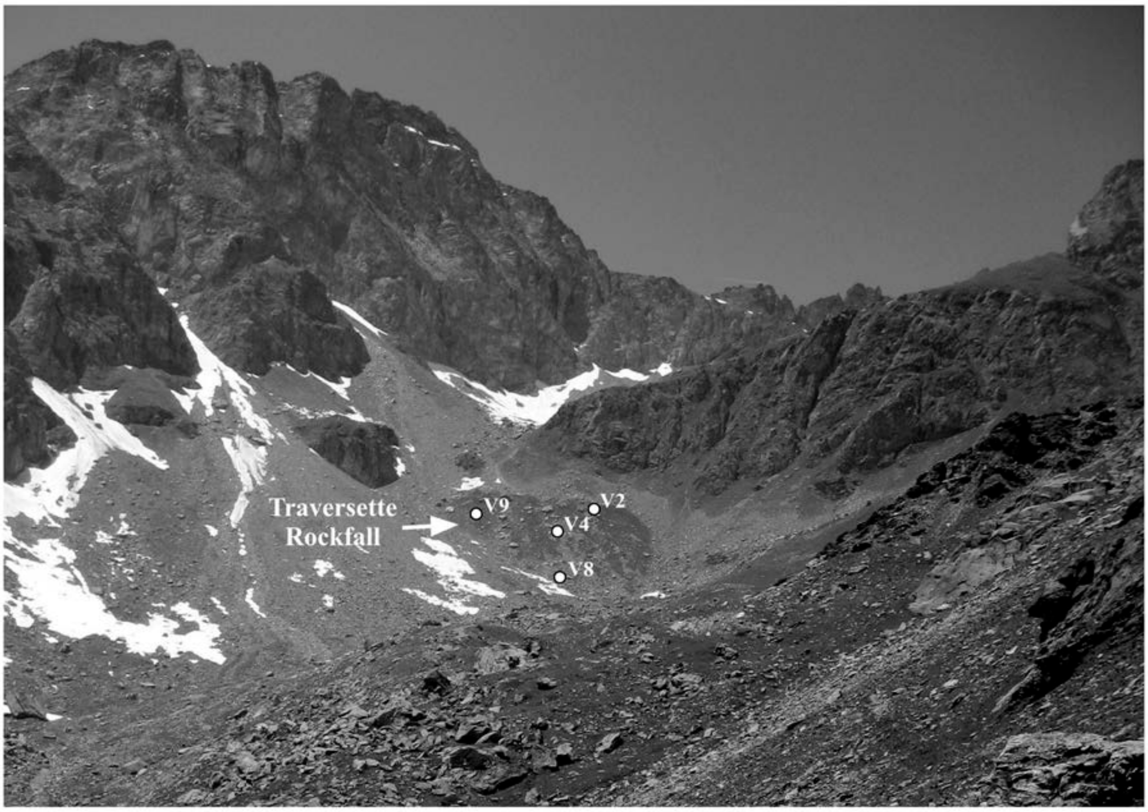

Figure 2. View across the rockfall looking south. Vegetated areas on both side of the complex deposit approximately comprise the older rockfall member mentioned by Polybius. The fresh unvegetated area is the younger Neoglacial-age deposit.

2. REGIONAL BACKGROUND

The Alps straddle the plate boundary between Europe and Africa which continues to converge today (Tricart, 1984). The Western Alpine arc shared by Italy and France, a broad scale tectonic structure developed along 300 km of longitude with a width of 150 to 200 km, produces a marked asymmetry with the inner eastern slope much steeper than the outer western one. Nearly every researcher who has studied the Hannibal Invasion has focused on this character of the geological structure, which makes for a difficult descent onto the Po River plains. The orogen asymmetry expressed in the topography originates from the subsurface structural asymmetry of the collision wedge, with repeated outward-directed (west) tectonic transport, the net result of which produced a curvature responding to unequal shortening of the European paleomargin at the western tip of the *Adria* indenter, an African promontory. The main mountainous relief, oriented NE-

SW in the north and NW-SE in the south, outlines a succession of fold-thrust structures developed deep into the Pre-Mesozoic crystalline basement and Meso-Cenozoic sedimentary cover (Fig.1). Transverse valleys across these thrust sheets, through which Hannibal marched to reach the high col, comprise syn-and post-collision faults, but also older faults inherited from the initial rift structure.

The core of the Western Alpine arc comprises a thick pile of metamorphic rock, derived from the subduction of the Tethyan Ocean below its European passive margin, followed by the collision between this margin and the conjugate margin, the Adria margin, on the African side. During this mainly Cenozoic collision, several shortening phases resulted in folds and thrusts, producing the parabolic geometry of the inner mountain belt. From the late Cenozoic onward (Tricart *et al.*, 2006), this polycyclic structure of folds and faults underwent gravitational collapse, which resulted in transtensional and extensional faulting parallel and transverse to the mountain belt. This late Alpine fault net remains active today and is mainly responsible for the location of major valleys, *i.e.* the Upper Po and Guil catchments. Thus, the geometry of the Alpine fault net provides insight as to the nature of surface geomorphological features and why drainage systems appear more complex within the internal arc. It is within the main valley of the Upper Po River that the Traversette Rockfall is located, its origin most likely intricately linked to fault movements following deglaciation.

3. METHODS

Rock and soil samples were subjected to various physical, chemical, microbiological and mineralogical analyses as indicated below. Pebbles were collected for lithologic identification and weathering rind analysis to assess relative age following procedures outlined by Mahaney (1990).

Soils were collected and horizons identified following Birkeland (1999); soil colors follow Oyama and Takehara (1970). Soil samples were subjected to laboratory tests including particle size (Day, 1965) by hydrometer, conductivity to determine salt content, and pH was determined by electrode. The pH and conductivity probes were calibrated before experimentation and the calibration was re-checked at the end and at regular intervals during the measurements. No 'drift' occurred. Carbon, nitrogen and hydrogen contents were determined using an Exeter Analytical CE 440 elemental analyzer. Soil samples were ground into a fine powder and milligram quantities were analyzed for C, H and N contents. Samples were run in duplicate.

The clay fraction was studied for mineral composition by means of powder XRD using a Bruker 8D diffractometer with Ni-filtered CuKά radiation. Scanning steps for oriented samples were 0.02° 2θ from 2 to 55° 2θ. A semi-quantitative mineral composition was determined from peak integral intensities of chlorite, illite-vermiculite, mica+illite, kaolinite, talc and smectite, multiplied by factors of 1, 0.35, 2, 1.4, 0.2, 0.2 respectively (Whittig, 1965; Kalm et al., 1997).

Sand fractions were imaged by light microscope to determine the composition of the source minerals and their weathered state. These samples were wet washed during particle size analysis, the sands recovered following dry sieving. Approximately 300 grains per sample were examined, and a select few were randomly chosen for microscopic analysis. From this population of grains a subpopulation was selected for more intensive investigation by Scanning Electron Microscope (SEM), Field Emission Scanning Electron Microscope (FESEM) and Energy-Dispersive Spectrometry (EDS) (see-Mahaney, 2002).

Separately collected samples of C/Cox and Cu horizons of the G3, V9 and additional moraine deposits were subjected to preliminary metagenomic microbial analysis. Sediment samples were taken under asceptic conditions for this purpose from the mid-point depth of respective soil horizons. Cu horizons were sampled approximately 5-cm below the top of the horizon. The samples were immediately stored on ice in the field and frozen at -20 °C upon return to the laboratory. Sediments were subject to total DNA extraction (Griffiths et al., 2000) and subsequently compared using DGGE (Density Gradient Gel Electrophoresis) analysis of 16S rRNA gene partial sequences (Muyzer *et al.*, 1993). The 16S rRNA gene is present in all bacterial isolated DNA, and as a 'housekeeping gene' has been widely used to define microbial phylogeny. Here populations of this gene in different samples were compared to assess the similarity between bacterial communities found between sites and within soil profiles. Statistical analysis of DGGE results was performed using cluster analysis based upon the unweighted pairwise grouping method with mathematical averages (UPGMA).

4. RESULTS

4.1 The Rockfall

The rockfall (cf. landslide described by Polybius) was said to measure 300 yards, approximately equivalent to 275 m, which is close to the actual size near the source bedrock where the broad apron of debris measures ~240 m (Fig. 2). Presumably erosion over the last 2.2 kyr has converted part of the mass to talus which envelopes the rockfall to the north and south. As shown in Fig. 2 the rockfall exhibits an older vegetated area with a resident Cryochrept paleosol of Late Glacial age contrasted against the younger and more voluminous mass of debris carrying a thinner Cryorthent which is largely lacking in significant vegetative cover. Cross sections through the rockfall yield finer debris in the older mass with pockets of large boulders, many with diameters of >1 m with similar lichen cover compared to clasts in the larger and younger deposit. However, coarse clastic material in the older deposit displays a rough tank and tor microtopography contrasting with clasts in the younger deposit which are fresher. In addition to degrees of weathered clast surfaces, pebble rinds at two sites [V8 (Neoglacial) and V9 (Late Glacial)] provide relative age estimations (Table 1).

Table 1. Weathering rind data for sites V8 and V9, Traversette Rockfall, Italian Alps. Rind measurements are in mm. based on populations of 50 at each site. Maximum counts are the Σ of total rind thicknesses at each site. Internal weathering is a summary of the number of clasts carrying internal discoloration in each population.

Site	Maximum count	Mean maximum	Minimum count	Mean thickness of minimum rind	Internal weathering
V8	15	0.30	0	0	4
V9	152	3.04	9	0.18	28

4.2 Weathering Rinds

Rock rinds collected and measured at two sites—V8 and V9—provide useful data on the relative age of the surficial materials at each site. As relative age indicators, clasts lying in residence on deposit surfaces record weathering stresses transmitted to them by the subaerial atmosphere and local biosphere, the chemical front deepening with rinds becoming thicker over time (Mahaney et al., 2013). A 1-mm thick rind means that 1 million nanometers of atomic space has recorded all environmental perturbations occurring over the lifetime of a clast resident at the site. Thus, because weathering rind development is differential across a clast (Mahaney et al., 2012), a single rind usually produces a maximum and minimum thickness (Mahaney, 1978). Therefore, a rind population of 50 clasts produces some variability in rind thickness which requires the maximum and minimum measurements to be reduced to mean figures. Hence, the values for V8 and V9 as shown in Table 1 record a considerable difference between the Neoglacial and Late Glacial sites. The rind mean maximum thickness at V9 (Late Glacial) is 10 times the mean maximum rind at V8, a measure of the relative difference between times of emplacement. The mean minimum rinds are different as well with positive values at V9 and nil at V8. This trend is similar to rind measurements taken at other middle latitude sites in North America (Mahaney, 1978) where Neoglacial vs. Late Glacial sites have been differentiated on the basis of mean minimum rind growth.

4.3 The Soils/Paleosol

The soils (Fig. 3) in the younger rockfall member (V2, V4 and V8) and the paleosol in the older member (V9) were analyzed to determine if degrees of difference of normal soil properties might reveal age differences. The V2 and V8 profiles near the toe of the younger deposit are of similar depth compared with V4 higher up in the deposit. With thickness running between 22 and 29 cm and Ah/C-Cox/Cu profiles, the soils narrowly permit classification into the Cryorthent (NSSC, 1995) or Regosol (Canada Soil Classification, 1977) orders. Color ranges from 10YR 2/1 in the Ah horizons to 10YR 6/1 in the C and 10YR 4/3 in the Cox horizons, the hue in the latter containing sufficient pigment to suggest release of secondary oxides and hydroxides. The Cu horizon color is 2.5Y 5/2, within the normal hue of unweathered parent material.

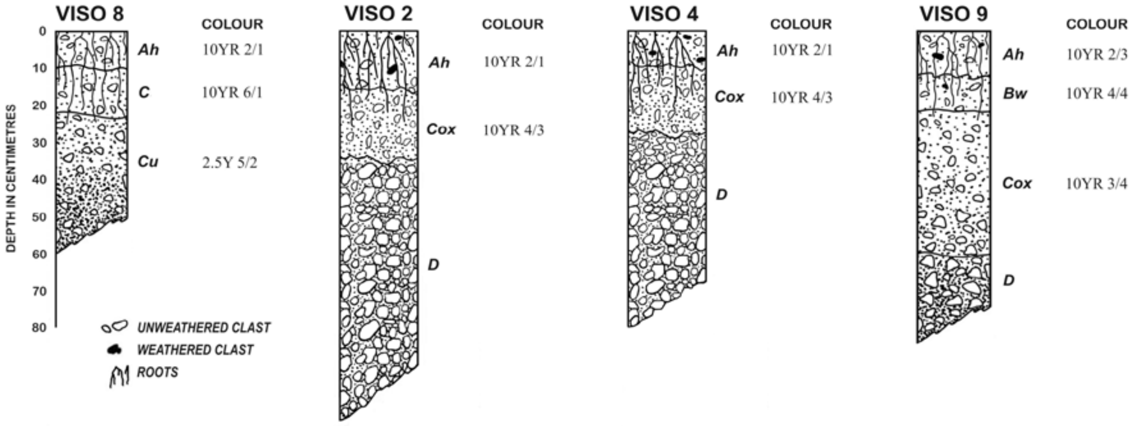

Figure 3. Soil/paleosol profiles within the rockfall. The soils (V2, V4 and V8) have probably experienced minor climatic perturbations during the later Neoglacial while the Late Glacial paleosol has experienced both a postulated airburst impact (Mahaney and Keiser, 2013) and large scale climatic swings from the Late Pleistocene to postglacial warming during the Holocene.

Field textures remain steady throughout the pedons as pebbly to coarse pebbly sandy loam in the Cu in V8 where parent material is present. Structure is massive in the lower horizons becoming granular in the Ah group. Moist consistence is massive in the C-Cox/Cu becoming friable in the Ah horizons. All horizons are nonplastic throughout and nonsticky in the C-Cox/Cu and slightly sticky in the Ah suite of samples. Roots extend through into the C horizons.

The 22-cm depth of V8 is the thinnest of the three profiles analyzed which indicates the maximum degree of weathering in the younger rockfall member is variable depending upon microenvironment. The other two sites display somewhat thicker profiles, as well as different approximations of the wetting depth in the surface mantle, *i.e.* the depth to which soil water penetrates to achieve alteration of fresh mineral material into soil. The change in color in the V8 profile follows the same trend as in V2 and V4, exhibiting the standard soil color nomenclature of Oyama & Takehara (1970), with YR equating to yellow red hues followed by value and chroma making a sharp contact with the yellow (2.5 Y) hue of the parent material. The surface color is black grading downwards to dull yellowish brown in the C/Cox horizons, the colors indicating a build-up of humus at the surface and release of oxides and hydroxides at depth, an arrangement that may well be compatible with the alpine environment for this latitude and elevation, as well as the middle Neoglacial age of the material. Undulating horizon contacts shown in Fig. 3 between the Ah and C/Cox horizons suggest at least minor freeze thaw activity, not unexpected given the altitude of the site and low clay percentages. The color in the Cox horizon as the 'ox' designation implies weak oxidation of mineralic material with colors in the 10YR 4 and 5 range.

Soil structure, which relates to the degree to which fine particles adhere together to form larger aggregates and which takes time to form (Mahaney, 1990), is present only in the Ah horizon in the form of granules, the grade of development similar to what exists in the V2 and V4 profiles described above.

The V9 profile in the outer and older rockfall member is a Cryochrept (NSSC, 1995) with an Ah/Bw/Cox/Cu profile, of 60-cm thickness and formed over an interlocking network of coarse clastic rockfall debris. Colors are decidedly stronger, ranging from 10YR 2/3 in the Ah and 10YR 4/4 in the Bw horizon, to 10YR 3/4 in the Cox. Field texture is similar to the younger soils with pebbly silty loam in the Ah grading downward to pebbly sandy loam in the Bw and Cox horizons. Soil structure shows an upgrade over the younger profiles with stronger granular clods in the Ah, weak blocky forms in the Bw and massive in the Cox. Moist consistence is similar to that in the younger pedons with a friable condition in the Ah becoming very friable with depth. Plasticity remains nil, as in the younger profiles, becoming slightly sticky in the Bw and Cox horizons. The Ah/Bw horizon contact shows minor convolutions indicating some frost heave. Roots reach 2 mm in diameter, somewhat larger and more frequent than in the younger soils.

4.4 Particle Size

Particle size (Table 2) was studied in order to further assess the effects of age and weathering on the weathered cover sediments in question. Despite a minimum number of samples, the resulting linear particle size curves are characteristic of heterogeneous material produced by large scale mass wasting events, similar to curves generated by till. While clay content in the middle Neoglacial soils is low (~2-3% in all horizons), and somewhat higher in V9 (3.5%), overall the size distributions are not unusual with alpine soils and paleosols. There is no demonstrable downward movement of fines within the profiles. The humus-rich Ah horizons are distinct from the C/Cox horizons in all profiles in that there is approximately higher silt in the subsurface than at the surface, which argues against aeolian influxes of fine grained material. Calculated mean phi values, determined on the 25th, 50th and 75th percentiles support the grade size results reported for each silt grade size. The center-of-gravity measurements of 2.3 to 3.5 mean ø indicate only minor downward shifts in clay which may be the result of high porosity or settling-out processes in coarse grained rockfall deposits rather than weathering over time.

Table 2. Particle size distributions in soils and paleosols of the Traversette Rockfall.

Site	Horizon	Depth (cm)	Sand (2mm-63μm) (%)	Silt (63-2 μm) (%)	Clay (<2 μm) (%)	Mean Phi[a]
Viso2	Ah	0-15	70.9	27.1	2.0	2.3
	Cox	15-35	64.9	33.4	1.7	3.0
	D	35+	--	--	--	--
Viso4	Ah	0-9	69.6	29.1	1.3	2.8
	Cox	9-27	60.5	37.2	2.3	3.0
	D	27+	--	--	--	--

Viso8	Ah	0-10	63.8	35.2	1.0	2.9
	C	10-22	63.7	34.7	1.6	3.0
	Cu	22+	63.7	34.5	1.8	3.0
Viso9	Ah	0-12	64.5	32.5	3.0	3.1
	Bw	12-22	54.9	44.1	1.0	3.5
	Cox	22-60	52.9	44.1	3.0	3.5
	D	60+	--	--	--	--

[a] Mean phi is calculated: Σ= 25th + 50th + 75th %/3.

4.5 Clay Mineralogy

Distinctions between the Ah and C horizons of the young member profiles (V2, V4 and V8) are minor as indicated in Fig. 4. Similar concentrations of illite in both horizons of V4 and V8 indicate no chloritization of illite, as seen in other Neoglacial profiles (Mahaney, 1978), but rather inheritance from the local mica schist bedrock. The presence of illite-vermiculite with greater concentrations in the C horizon of V4 suggests a possible link with boreal forest species which may have inhabited the site in the Atlantic and sub-Boreal chronozones (see pollen section below). The small concentrations of amphibole (hornblende) may result from airfall influx or the local source rock. Minor pedogenic modification of the mineral composition of the soils supports a young mid-Neoglacial age for profiles V2 - V8. The V9 profile is similar to V4 and V8 but with slightly greater chlorite which could relate to chloritization of illite. Quartz and plagioclase are variable among the three profiles and in trace quantity only but overall do not allow discrimination between sites.

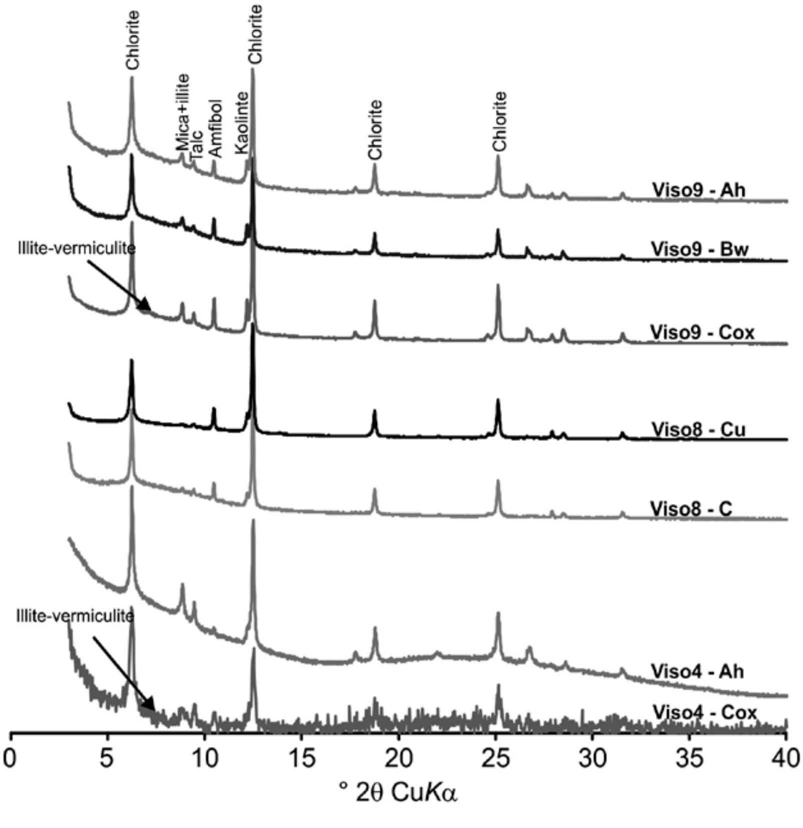

Figure 4. XRD traces across various horizons in the younger rockfall member soils and the V9 paleosol.

4.6 Soil Chemistry

Soil chemical properties of profile V8 (Neoglacial) and V9 (Late Glacial) (Table 3) provide a database on the compositional differences between deposits in the rockfall. Aside from the taxonomic differences—Cryorthent (V8) to Cryocrept (V9)—pH is strongly acid in both profiles with only very slightly greater pH in the younger system. Down profile in both systems pH decreases with increased leaching time becoming somewhat more acidic in the older V9 profile. Electrical conductivity, as a measure of total salt, is variable in the two systems. In V8 total salt decreases with depth into the C horizon, increasing in the parent material presumably sourced from the bedrock. The distribution in V9 depicts a slow decrease with depth with overall lower amounts possibly produced by increased leaching in the older profile. Organic carbon in both profile epipedons (Ah horizons) yield similar concentrations suggesting that C/N dynamic equilibrium is reached in less than ~3 ka and possibly sooner. Downward trends of C/N in both profiles are similar.

4.7 Microbiology

A comparison of the microbiological eubacteria populations was performed using DGGE analysis of the 16S rRNA genes in a number of C/Cox and Cu horizons – including the V8 and V9 C/Cox horizons. Soil microbiological population structures are complex, and the individual components of a population are influenced by a wide range of factors including the immediate microclimate chemical/physical components in the sediment matrix and the age/history of the sediment. With this multitude of factors in mind a DGGE (density gradient gel electrophoresis) comparison was used to try and show if the younger V8 C/Cox population differed to any extent from the apparently older V9 C/Cox, other C/Cox sediments in the area, and the associated Cu sediments. In Fig. 5 a dendrogram shows the close relation of the eubacterial populations in these sediments. Two key factors are apparent: i) That the C/Cox *vs.* Cu horizons have distinctly different populations; ii) That the Viso 8 population is less similar to the other C/Cox populations studied in this experiment; iii) that the C horizon in V8 is distinct from V9, the latter showing a close correlation with other C horizons of Late Glacial age (15-13 ka) in soil profiles of the Viso area. Point (ii) is consistent with a view that V8 represents younger sediment – perhaps characterized by less weathering and therefore differing geochemistry in the microenvironment, or – in the absence of a Bw horizon – greater exposure to micronutrients percolating down from the Ah horizon.

Table 3. Selected chemical parameters for soil (V8) and paleosol (V9) in the Traversette Rockfall.

Site	Horizon	Depth (cm)	pH (1:5)	Conductivity μS/cm^{-1}	Organic C (%)	TKN (%)
V8	Ah	0-10	5.6	56.0	6.49	0.49
	C	10-22	5.2	19.3	1.60	0.04
	Cu	22+	5.6	116.8	0.69	0.00
V9	Ah	0-12	5.4	41.0	6.79	1.01
	Bw	12-22	4.9	26.1	1.89	0.07
	Cox	22-60	5.1	4.9	1.30	0.06
	D	60+	--	--	--	--

4.8 Scanning Electron Microscopy

Randomly selected mineral grains from the various horizons of profile V4 and V9 were subjected to analysis by SEM-EDS to assess their weathered state. The results for V4, previously published by Mahaney et al. (2010a) indicate that over 80% of the grains contain dense accumulations of adhering particles, appearing indurated on the mineral surfaces (Mahaney et al. 2010a; Figs. 9A and B). There does not appear to be any cementation of grains or melted grains in the younger profile, but none is expected given the young age of the V4 soil. Most grains exhibit minor subparallel fractures and abrasion features as well as fracture faces, the latter probably resulting from bedrock release by physical weathering. These microfeatures are strikingly similar to microtextures found in fine talus debris in other mountainous areas (Mahaney, 2002) and are quite distinct from microtextures related to other geological processes.

The indurated nature and lack of cementation of the matrix material in the younger rockfall lobe implies that Hannibal's engineers could segregate large clasts to provide a wide pathway through the rubble. Removing the clasts by levering them out position was probably difficult given the physical state of the infantry and the overall decline of morale.

Microtextural analysis of the sand fractions in the older rockfall lobes reveals a multitude of grains (Fig. 6A) with adhering particles fused together from a high temperature event, presumably the black mat impact of 12.8 ka as documented nearby in the upper Guil River Catchment (Mahaney and Keiser, 2013). The EDS spectrum shown in Fig. 6B depicts the common melted and fused nature of small carbon and Fe spherules welded to a very fine sand pyroxene grain.

4.9 Rockfall Reconstruction: Late Glacial to Mid Neoglacial age.

Lichen growth (total cover and maximum diameters of *Rhizocarpon* section *geographicum*) are close to maximum, and hence, near longevity on rock outcrops above the rockfall, which means that a lichen trimline that might delineate a younger bedrock source area for the Neoglacial debris does not exist.

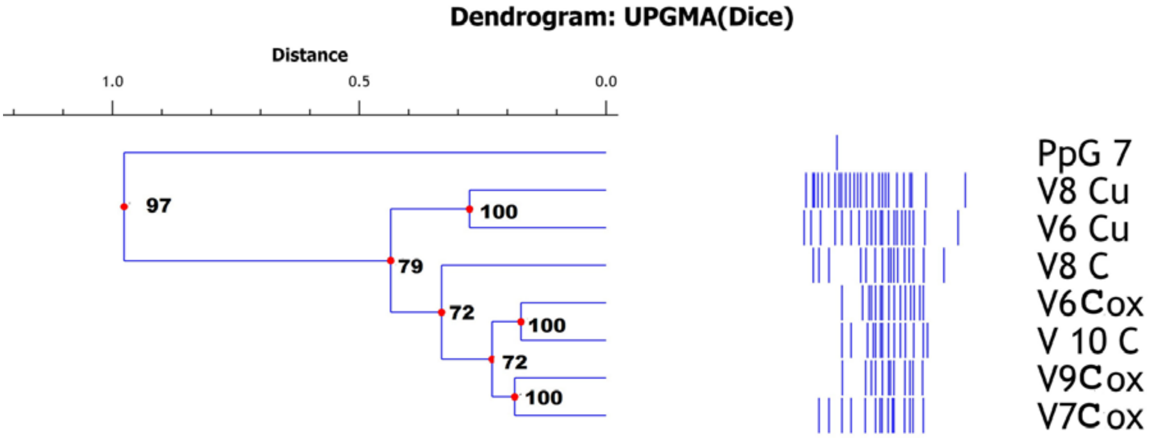

Figure 5. Microbiology analysis consisting of a DGGE comparison of the eubacterial 16S rRNA gene populations from two Cu horizons, and 4 C/Cox horizons – including V8 and V9—of a suite of Late Glacial paleosols and soils. The data can be interpreted to show how, relatively, closely related the populations are in these 8 samples. The pp G7 negative control represents a single laboratory *Pseudomonas putida* strain (a common soil bacterium) for comparison.

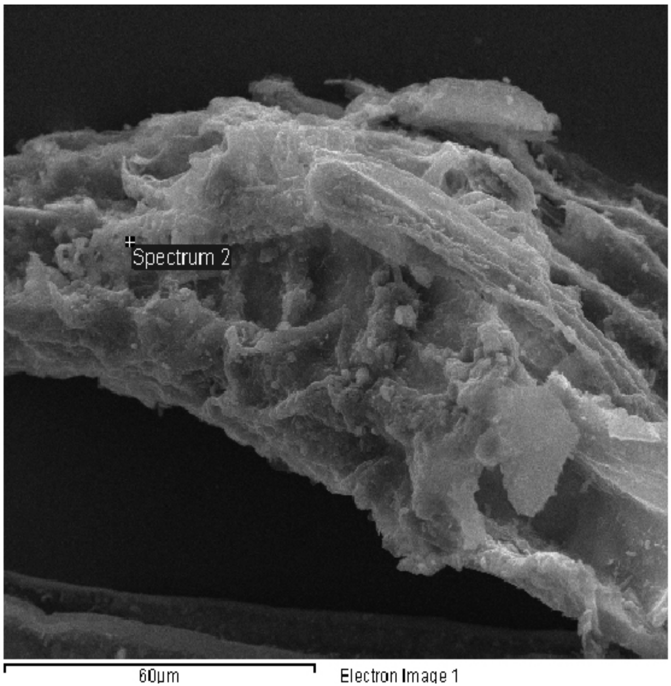

Figure 6. A, SEM image of a pyroxene of very fine sand size in the outer and older lobe of the Traversette rockfall. The sample contains a multitude of welded pyroxene, quartz and Fe spherules, mostly coated with carbon from wildfire that engulfed the site following a cosmic airburst at 12.8 ka; The grain is highly fractured and covered with adhering particles presumably from the mass wasted event.

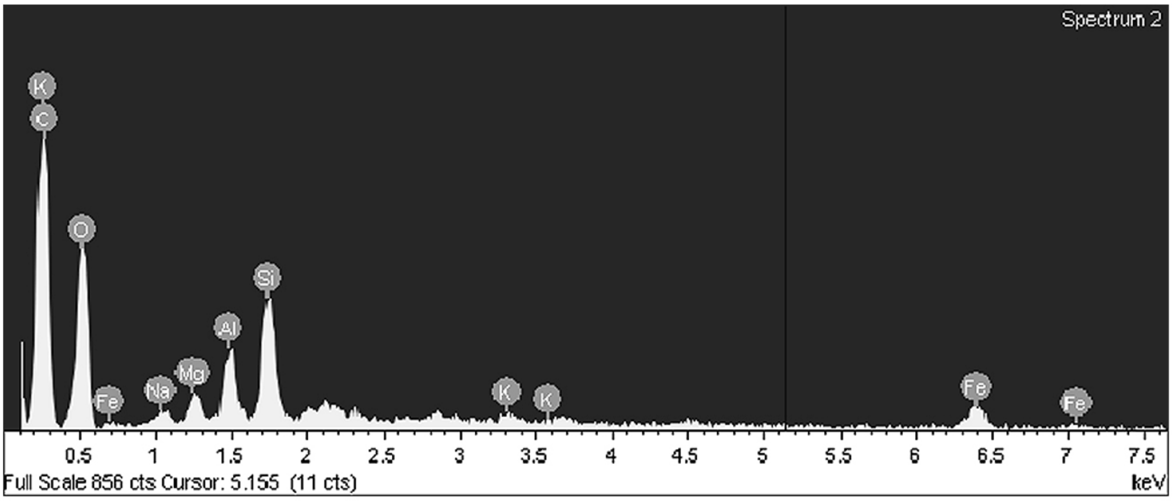

Figure 6B. EDS of a welded grain showing a typical augite signature (Ca unmarked) along with very high carbon. The small concentration of Na may be related to acmite fused with augite.

Moreover, maximum diameters of *R. geographicum* on the bedrock outcrop reach 95 mm, similar to maximum diameters on both the younger and older rockfall debris members. Lichen cover, somewhat higher on the rockfall material than on the bedrock walls, ranges from 60 to 75%, which is at or close to longevity at the nearest locale (i.e. Mt. Blanc, Mahaney, 1991). The variation in lichen cover, with lower values on bedrock walls, is most probably due to aspect, wind direction, prevalent ice crystal blasting and moisture variations. In places, numerous plumes of *Xanthoria elegans* lace bedrock and rockfall surfaces where bird perches exist, associated lichen fertilized by various avian species, as documented elsewhere (Julig et al., 2012). Whilst the fertilized colonies of *Zanthoria* show inordinately high percent cover this does not seem to have affected the growth and spread of *Rhizocarpon.*

Moreover, a close scrutiny of rock outcrops above the rockfall does reveal a weathering trimline; heavy oxide coatings above on the recessed ridge slope 30 m above the upper deposit and lighter tonal contrast below suggests the younger age probably outlines the source area for sediment in the younger rockfall member. While weathering characteristics allow relative age discrimination, lichen cover and maximum lichen diameters reveal that both rockfall deposits are older than lichen longevity, both on the exposed bedrock wall above the upper rockfall debris and in the general area (Pech, et al., 2003). The lichen cover by itself argues for an age >2 ka (Mahaney et al., 2010a).

4.10 Paleo-Vegetation Reconstruction

The vegetation proxies from small lakes reveal that the subalpine belt was mostly covered by woodland until the Middle Age (1800-1300 cal yr BP) depending on sites. The upper timberline, dominated by cembra pine, occupied a position some 300 and 500 m above the present-day timberline before 2000 cal yr BP, although it had already begun to shift downslope approximately 4000 cal yr BP (Carcaillet *et al.* 1998; Ali et al. 2005; Carcaillet and Muller 2005). Using palynological data as a guide it is probable forest reached to an elevation of ~2300 m or just below the rockfall. Recovered core data indicate that with sufficient biomass, subalpine wildfires occurred infrequently at a rate of 3-5 fires/1000 years. The conversion to subalpine meadow and short grassland occurred after 2000-1800 cal yr BP producing a progressive decrease of tree-pollen frequency and abundance (Genries et al. 2009) associated with fires resulting from fuel-suppression (Carcaillet *et al.* 2009) resulting from a change of land-use occupied by cattle and sheep or from onset of the sub-Atlantic chron in the late Neoglacial. Both plant macro-remains from several sites and pollen data (*e.g.* David 1995; Genries et al. 2009) demonstrate that forest was the dominant community until the widespread distribution of grass between 2000-1300 cal yr BP. When Hannibal and his army passed the Traversette Rockfall, scattered trees were likely present just below the rubble sheet. The climate was more or less similar to today.

5. DISCUSSION

These data indicate that deposit morphology clearly shows a major difference between the two members of the Traversette Rockfall, an older deposit deeply buried by a second mass of somewhat greater volume. When Polybius visited the site the younger deposit may have had a steeper slope than today with larger clasts near the bedrock wall. The deposit may also have had a narrow path extending to the north which would have had to be widened, ballast fixed in place to allow the passage of animals. To the starving troops this must have seemed a daunting task. Scott-Kilvert's (1979) translation of Polybius makes this point crystal clear: 'He (Hannibal) set his troops to work on the immensely laborious task of building up the path along the cliff. However in one day he had made a track wide enough to take the mule train and the horses; he at once took these across, pitched camp below the snow-line and sent the animals out in search of pasture. Then he took the Numidians and set them in relays to the work of building up the path. After three days of this toilsome effort he succeeded in getting his elephants across, but the animals were in a miserable condition from hunger. The crests of the Alps and the parts near the tops of the passes are completely treeless and bare of vegetation, because of the snow which lies there continually between winter and summer, but the slopes half-way down on the Italian side are both grassy and well-wooded, and are in general quite habitable.

No doubt the present trail extending from an old Italian Army barracks higher up the mountain to the switchback leading into the lower valley has been repaired and re-ballasted several times, mainly with rock taken out of the younger rockfall member. Taking Polybius' account at face value it is difficult to understand the recent criticism of Mahaney et al. (2010a) by Kuhle and

Kuhle (2012) who argue Hannibal cut a path across ledges there being no landslide when it is clear from Polybius' account that the landslide was the obstacle. Otherwise why would he have identified the landslide and 'building up a path' which surely refers not to carving out a ledge route but shoring up a path through the landslide, **cf. rockfall**. The illogic of such a criticism is reinforced all the more by reference to the Col du Clapier (Fig. 1A), 60 km north of the Traversette, considered by Kuhle and Kuhle (2012) as the favored route of passage of the Punic Army, an entrance point to Italia that does not match the environmental description in any of the ancient texts (Mahaney, 2008).

The variation from a clast-dominated matrix or open network of coarse material below (D horizon) to a more dispersed arrangement of smaller stones mixed with sand and finer material above suggests a special microenvironment where plants have stabilized the subsurface. For the most part the soils, even the one paleosol, described here do not contain Cu horizons of fine grade size material. Soil thickness and horizon designation in the younger member group of soils depends upon microenvironment and position in the deposit. The V2 profile in the upper rockfall formed over an open network of coarse clastic sediment, presumably supported and stabilized by plant roots. Lower in the rockfall the V4 and V8 profiles carry similar profiles but with occasional collection of silty sand containing a Cu horizon making it possible to study the transition of parent material into soil. This transition clearly shows little change in particle size, the main weathering products confined to color changes marking the production of oxides and hydroxides. Contrasting these young member soils with the older paleosol at V9 is highlighted by the production of a fully formed Cryochrept soil of twice the depth and somewhat stronger color indicative of greater chemical weathering but with similar particle size distributions, percent clay content and clay mineral composition. Otherwise there is little to discriminate between the two groups.

A search of recovered soil for telltale flakes of charcoal, evidence that might support Livy's contention that Hannibal fired rock on the lee side of the Alps, proved unsuccessful. As discussed, the only route with fired bedrock outcrops lies through the Col du Clapier, 50 km to the north of the Col de la Traversette (Sodhi, et al, 2006; Mahaney et al., 2007; Mahaney, 2008).

Even though soil stratigraphy—sequences of soils used to date underlying deposits---in the Western Alps has never been established (see Egli, *et al.,* 2003) it is possible, in a general way, to correlate the younger soil in the Traversette rockfall with places further afield, where approximate ages of soils are known (Mahaney, 1991). Using depth of weathering, A/C soil horizon assemblage, soil colors and inferred organic and weathering components, textural gradations down-profile, and low grade of soil structure it is likely these profiles carry a Neoglacial age, most probably between 2000 and 4000 years. While it is difficult to tie these profiles directly to Hannibal, it is likely he crossed over the younger profiles on the march into Italia.

The older paleosol (V9), is the one profile selected as representative of the profile expression in the older rockfall member. As with the younger soils, pH in the V9 profile is strongly acidic, and contains somewhat greater H+ ion content in the Bw horizon. The total salt content decreases down profile from higher concentrations in the Ah horizons where nitrates are released by vascular plants to lesser amounts released by leaching. Similarity of pH in all surface horizons indicates that soils are at or close to dynamic equilibrium at all sites in the younger rockfall member.

6. CONCLUSIONS

The 2200-yr old description by Polybius of the rockfall that blocked Hannibal and the Punic Army on their high-col crossover to Italia during the great invasion has been the subject of debate by classicists for centuries. Polybius' first-hand account depicts a two-tier mass wasted deposit of spectacular size and scope, one sufficient to block cavalry horses, draft animals and elephants requiring some three days for his engineers to clear, ballast and forge a path through to a regrouping area in the lower valley. Livy, echoing Polybius a century and half later and relying on other sources, described a single mass wasted deposit blocking the Carthaginians, and noted it had a width of 300 yards. No doubt Polybius's description is preferred over Livy as the great general actually followed the invasion route and was presumably on site describing the 'landslide' in great detail.

Whilst little attention has been paid to the size and scope of landslides or rockfalls on the exit routes of the major passes, the identification of the Traversette Rockfall as the only sizable mass wasted deposit matching Polybius's description, supports de Beer (1969) who, for a variety of reasons, contended that Hannibal crossed the highest of cols in the Western Alps to gain entrance to Italia. The stratigraphic data presented here not only supports de Beer but also lays out the geologic database that clearly shows the rockfall size and scope as well as differentiation of the two rockfall members, the oldest assigned to the Late Glacial stage of the Last Glacial Maximum and the youngest to the middle Neoglacial. What is most crucial here is that for the first time an area comprising some 240 m x 20 m is fertile ground for geoarchaeological exploration. It is impossible to imagine an army the size of Hannibal's force, one engaged in clearing and ballasting a path through a rubble sheet, not losing or discarding implements and personal accoutrements. As a prime target for such exploration, on a similar scale to the bivouac in the Upper Guil River to the west of the high col and the regrouping area of the Upper Po River, the rockfall is a prime area for a ground penetrating radar / geophysical metal detection survey.

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REFERENCES

Ali, A.A., Carcaillet, C., Talon, B., Roiron, P. and Terral, J.-F. (2005) *Pinus cembra* (arolla), a common tree in the inner French Alps since the early Holocene and above the present tree line: a synthesis based on charcoal data from soils and travertines. *Journal of Biogeography*, vol. 32, 1659-1669.

Bagnall, N. (1999) *The Punic Wars*. Pimlico, London, 347 pp.

Birkeland, P.W. (1999) *Soils and Geomorphology*, Oxford University Press, Oxford, U.K., 430 pp.

Canada Soil Survey Committee (1977) *Soils of Canada* 1. Agriculture Canada, Ottawa. 243 pp.

Carcaillet C. and Muller S.D. (2005) Holocene tree-limit and distribution of *Abies alba* in the inner French Alps: anthropological or climatic changes? Boreas, vol. 34(4), 468-476.

Carcaillet, C., Talon, and B., Barbero, M. (1998) *Pinus cembra* et incendies au cours de l'Holocène, 300 m au-dessus de la limite actuelle des arbres dans les Alpes du nord-ouest. *Écologie*, 29, 277-282.

Carcaillet, C., Ali, A.A., Blarquez, O., Genries, A., Mourier, B. & Bremond, L. (2009) Spatial variability of fire history in subalpine forests: large and local scale processes during the Holocene (from natural to cultural regimes). *Ecoscience*, 16(1), 1-12.

Connolly, P. (1981) *Greece and Rome at War*. MacDonald and Co.,

Cottrell, L. (1992) *Hannibal Enemy of Rome*. Da Capo Press, N.Y., 257 pp.

David, F. (1995) Vegetation dynamics in the northern French Alps. *Historical Biology*, vol. 9, 269-295.

Day, P. (1965) Particle fractionation and particle size analysis, In, C.A. Black, ed., *Methods of Soil Analysis*, Madison, Wi., Am. Soc. Agronomy, 545-567.

de Beer, G. (1967) *Hannibal's March*, Sidgwick and Jackson, London, 164 pp.

de Beer, G. (1969) *Hannibal.* The Viking Press, N.Y., 320 pp.

Dodge, T.H. (1891) *Hannibal,* Houghton Mifflin, N.Y.,

Egli, M., Mirabella, A., Sartori, G. and Fitze, P. (2003) Weathering rates as a function of climate: results from a climosequence of the Val Genova (Trentino), Italian Alps, *Geoderma,* vol. 111, 99-121.

Genries A., Muller S.D., Carcaillet C., Mercier L. & Bircker L. (2009) Local-scale processes control spatial variability of subalpine vegetation trajectories during the Holocene. *Ecoscience*, vol. 16 (1), 13-22.

Griffiths, R.I., Whiteley, A.S., O'Donnell, A.G., and Bailey, M.J. (2000) Rapid Method for Coextraction of DNA and RNA from Natural Environments for Analysis of Ribosomal DNA- and rRNA-Based Microbial Community Composition. *Applied and Environmental Microbiology*, 66(12), 5488-5491.

Julig, P., Mahaney, W.C., Kalm, V., Earl-Goulet, J. (2012) Geoarchaeological importance of Subarctic bird perches dated by turf mound accumulation and identified by lichen plumes. *Polar Record*, doi:10.1017/S0032247412000368.

Kalm, V., Kriiska, A. and Aruväli, J. (1997) Mineralogical analysis applied in provenance studies of Estonian Neolithic pottery. — Eesti TA Toimetised. *Geoloogia*, vol. 1, 16–34.

Kuhle, M., and Kuhle, S. (2012) Hannibal gone astray? A critical comment on W.C. Mahaney et al., 'the Traversetted (Italia) rockfall; geomorphological indicator of the Hannibalic invasion route, *Archaeometry*, vol. 52 (1), 156-172.

Lancel, S. (1999) *Hannibal,* Blackwell, Oxford, 243 pp.

Lazenby, J.F. (1998) *Hannibal's War,* University of Oklahoma Press, Norman, 340 pp.

Livy, trans. Aubrey de Sélincourt (1972), *The War with Hannibal,* Penguin, London, U.K, 711 pp.

Mahaney, W.C. (1978) Late Quaternary soil stratigraphy in the Wind River Mountains, western Wyoming, In. W.C. Mahaney ed., *Quaternary Soils*, Geo-Abstracts, Norwich, UK, 223-264.

Mahaney, W.C. (1990) *Ice on the Equator*, Wm. Caxton Ltd., Ellison Bay, Wisc., 386 pp.

Mahaney, W.C. (1991) Later Pleistocene and Holocene glacial chronology at Chamonix and Argentière, French Alps. *Zeitschrift für Geomorphologie*, vol. 35, 225-237.

Mahaney, W.C. (2002) *Atlas of sand grain surface textures and applications.* Oxford University Press, Oxford, UK., 237 pp.

Mahaney, W.C. (2004) A geological/topographical reconnaissance of Hannibal's invasion route into Italia in 218 BC. In, D.R. Caldwell, J. Ehlen and R.S. Harmon, eds., *Studies in military geography and geology,* Kluwer Academic Publishers, Dordrecht, Holland, p. 67-78.

Mahaney, W.C. (2008) *Hannibal's Odyssey: environmental background to the alpine invasion of Italia.* Gorgias Press, Piscataway, N.J., 345 pp.

Mahaney, W.C. (2012) Comments on Kuhle & Kuhle, Archaeometry, 'Hannibal gone astray' a critical comment on the Hannibalic invasion route. *Archaeometry*, doi:10/j.1111/j.1475-4754.2012.00724.x.

Mahaney, W.C. and Tricart, Pierre (2008) Hannibal's debacle in the Combe de Queyras in 218 BC: the unknown Gallic Commander, In *Military Geography and Geology: Histo-*

ry and Technology, C. P. Nathanail, R.G. Abrahart and R.P. Bradshaw, eds. ISBN number 095477429. Land Quality Management Press, Nottingham, U.K., p. 88-97.

Mahaney, W.C., Keiser, L. (2013) Weathering Rinds: Unlikely Host Clasts for Evidence of an Impact-Induced Event. *Geomorphology*, vol. 184, 74-83.

Mahaney, W.C., Milner, M.W., Sodhi, Rana, Dorn R.I., Boccia, S., Beukens, R.P., Tricart, Pierre, Schwartz, Stephane, Chamorro-Perrez, E., Barendregt, R.W., Kalm, Volli, Dirszowsky, Randy W. (2007) Analysis of burnt schist outcrops in the Alps: relation to historical archaeology and Hannibal's crossing. *Geoarchaeology, vol.* 22, 797-816.

Mahaney, W.C., Kalm, V., and Dirszowsky, R. (2008) The Hannibalic Invasion of Italia in 218 BC: geological/topographic analysis of the invasion routes, In *Military Geography and Geology: History and Technology*, C. P. Nathanail, R.G. Abrahart and R.P. Bradshaw, eds. Land Quality Management Press, Nottingham University, Nottingham, U.K., p. 76-86.

Mahaney, W.C., Kapran, B., Kalm, V., Tricart, P., Carcaillet, C., Barendregt, R.W., and Somelar, P. (2010a) The Traversette rockfall: geomorphological reconstruction and importance in interpreting classical history. *Archaeometry*, vol. 52, 156-172.

Mahaney, W.C., Tricart, P., Carcaillet, C., Blarquez, O, Ali, A.A., P., Agnant, J., Barendregt, R.W., Kalm, V. (2010b) Hannibal's invasion route: age-old question revisited with new scientific data. *Archaeometry*, vol. 52, 1096-1109.

Mahaney, W.C., Krinsley, D.H., Allen, C.C.R., Langworthy, K., Ditto, J., and Milner, M.W., Weathering rinds: archives of paleoenvironments on Mount Kenya, East Africa (2012), *Journal of Geology*, vol. 120, no. 6, 591-602.

Mahaney, W.C., Keiser, L., Krinsley, D.H., Allen, C.C.R., Dirszowsky, R., and Julig, P. (2013). Weathering rinds as mirror images of palaeosols: examples from the Western Alps with correlation to Antarctica and Mars *Journal Geological Society*, vol. 170, 838-847.

Muyzer, G., de Waal, E.C., and Uitterlinden, A.G. (1993) Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction-amplified genes coding for 16S rRNA. *Applied and Environmental Microbiology*, vol. 59(3), 695-700.

National Soil Survey Center (NSSC) (1995) *Soil Survey Laboratory Information Manual.* Soil Survey Investigations Report No. 45. Version 1.00. USDA, Washington, DC., 305 pp.

Oyama, M. and Takehara, H. (1970) *Standard Soil Color Charts,* Japan Research Council for Agriculture and Fisheries.

Pech, P., Jomelli, V., Baumgart-Kotarba, M., Bravard, J-P., Chardon, M., Jacob, N., Kedzia, S., Kotarba, A., Raczkowska, Z. and Tsao, C. (2003) A lichenometric growth curve in the French Alps: Ailefroide and Veneon valleys; Massifs des Ecrins. *Geodinamica Acta*, vol. 16, 187-193.

Polybius, trans. Ian Scott-Kilvert (1979) *The Rise of the Roman Empire,* Penguin, London, U.K., 574 pp.

Prevas, J. (1998) *Hannibal Crosses the Alps,* Sarpedon, Rockville Centre, N.Y., 232 pp.

Proctor, Dennis (1971) *Hannibal's March in History,* Oxford University Press, Oxford, U.K. 229 pp.

Renaud, J.P. (1996) L'itineraire transalpine d'Hannibal. La fin d'une enigma, *Archeologia. Prehistoire et Archeologie-Dijon, vol.* 324, 48-55.

Seibert, J. (1993) *Hannibal*, Wissenschaftliche Buchgesellschaft, Darmstadt, 75-134.

Sodhi, R., Mahaney, W.C., and Milner, M.W. (2006) ToF-SIMS applied to historical archaeology in the Alps, *Applied Surface Science, vol.* 252, 7140-7143.

Tricart, P. (1984) From passive margin to continental collision: a tectonic scenario for the Western Alps, *American Journal of Science*, vol. 384, 97-120.

Tricart, P., Lardeaux, J.-M., Schwartz, S., and Sue, C. (2006) The late extension in the inner Western Alps: a synthesis along the south-Pelvoux transect. *Bulletin de la Société Geologique de France*, vol. 177, 299-310.

Whittig, L.D. (1965) X-ray diffraction techniques for mineral identification and mineralogical composition. In Black, C.A., ed., *Methods of Soil Analysis*, V. 1, Madison, Wisc., Amer. Soc. Agronomy, 671-696.

Wilkinson, H. Spencer (1911) *Hannibal's March Through the Alps. Oxford at the Clarendon Press (*in a digitized form by internet archive with funding from Microsoft corporation 2007)