

# A Test of the MSEC Method for Paleoclimate and Intersite Correlations from Late Pleistocene/Holocene Cave Sites in Southern Europe: Results from Cova de les Cendres, SE Spain

BOOKS B. ELLWOOD <sup>1</sup>, VALENTÍN VILLAVERDE <sup>2</sup>, STEPHEN L. BENOIST <sup>1</sup>, JOAN BERNABEU <sup>2</sup>, FRANCIS B. HARROLD <sup>3</sup>, AND PAUL T. THACKER <sup>1</sup>

## RESUMEN

*En los últimos diez años, se han utilizado las mediciones de la susceptibilidad magnética (MS) de los sedimentos de los yacimientos arqueológicos en cueva para establecer correlaciones entre yacimientos y una estimación del paleoclima. Ello es posible porque la MS correspondiente a estos sedimentos es el resultado de los procesos activos del clima en el exterior de las cavidades y las variaciones en las propiedades magnéticas de los sedimentos, que*

## ABSTRACT

*During the last 10 years or so, magnetic susceptibility (MS) measurements of cave sediments from archaeological sites have been used for intra-site correlation and paleoclimate estimation. This is possible because the MS of these sediments results from climate processes active outside caves causing variations in magnetic properties of the sediments ultimately accumulating inside of caves. Once deposited, these materials are preserved and their stratigraphy*

---

<sup>1</sup> Department of Geology and Geophysics, Louisiana State University, E235 Howe-Russell Geoscience Complex, Baton Rouge, LA 70803 USA.

<sup>2</sup> Departament de Prehistòria i Arqueologia, Universitat de València, Avenida Blasco Ibañez, 28, 46010 Valencia, Spain.

<sup>3</sup> College of Natural and Social Sciences, University of Nebraska at Kearney, Kearney, NE 68849 USA.

*finalmente se acumulan en el interior de las cavidades. Una vez que se han depositado, estos materiales son preservados y su estratigrafía proporciona una información sobre el clima que puede ser inferida. En este trabajo, al usar la magnetosusceptibilidad, el método de cicloestratigrafía (MSEC) y la correlación gráfica, presentamos información sobre la Cova de les Cendres y situamos estos resultados en un marco paleoclimático que abarca los últimos 43.000 años (fechas BP sin calibrar) de la Europa meridional. Estos resultados correlacionan bien con otros indicadores independientes de clima.*

*Además, a causa de que los sedimentos de la parte superior de la Cova de les Cendres se depositaron relativamente rápidos, es posible observar cambios climáticos de escala ultra-fina en los datos de esta parte de la secuencia en la cavidad.*

#### **PALABRAS CLAVE**

*Magnetosusceptibilidad, muestras, clima, sedimentos, estratigrafía, cuevas, abrigos rocosos, España, Europa.*

*provides a climate proxy that can be extracted. Here, using the magnetosusceptibility event and cyclostratigraphy (MSEC) method and graphic correlation, we present data from Cova de les Cendres and place these results into a paleoclimatic framework for the last 43,000 years (uncalibrated BP) for southern Europe. These results correlate well with independent climate indicators. In addition, because sediments in the upper part of Cova de les Cendres were deposited relatively quickly, it is possible to see ultra fine scale climatic changes in the data set from this cave.*

#### **KEY WORDS**

*Magnetosusceptibility, samples, climate, sediments, stratigraphy, caves, rockshelters, Spain, Europe.*

## **INTRODUCTION**

We have used the magnetosusceptibility event and cyclostratigraphy (MSEC) method (Ellwood et al., 2001) along with graphic correlation (Shaw, 1964) to build a MSEC data base for southern Europe. This data base can be used for between site correlations and to estimate paleoclimate. MSEC is based on magnetic susceptibility (MS) measurements of sediment samples of micro-stratigraphic sample sets (continuous samples) recovered from well-documented archaeological sites. We have applied the method to Pleistocene and Holocene archaeological sites in Europe and the United States (e.g. Ellwood et al., 1994; Ellwood et al., 1995; Ellwood et al., 1996; Ellwood et al., 1997; Ellwood et al., 1998). The MSEC method for correlation

between cave sites utilizes the independent isotopic and cultural dates available from such sites and is based on the fact that regional, long-term climate cycles control, through pedogenesis, the magnetic material being created in the area. This material is then eroded and deposited within the cave, and the resulting stratigraphy is the source of the MSEC data set.

In unconsolidated samples found in protected archaeological cave sites from southern Europe, MS works as a proxy for climate because climate there controls the magnetic properties of the source sediments, primarily as the result of pedogenesis (see Mullins, 1977, for an early summary and Maher, 1998 for a more recent summary of magnetic products produced during pedogenesis). These sediments acquire an MS signature outside caves and are protected from further pedogenesis once deposited inside caves. At least for southern Europe, pedogenic processes produce abundant magnetic minerals such as maghemite, magnetite, hematite, and possibly greigite (Stanjek et al., 1994; Ellwood et al., 1997) during periods when climate is relatively warm and wet. This increases the MS signature in these sediments.

Clearly, climate is very important in the development of MS variations in many types of sediment. At low latitudes, such as in southern Europe during the Quaternary, climate controls on MS can be attributed to variations in magnetic mineral production during pedogenesis. Work by Tite and Linington (1975) and Singer and Fine (1989) showed that climate (both temperature and moisture) can have a significant effect on the MS, and that in general, warmer/wetter conditions enhanced the MS signature during pedogenesis. Besides maghemite, Maher and Taylor (1989) have shown that magnetite is readily produced during soil formation. (Much of the work concerning the production of ferrimagnetic minerals in soils has been summarized by Fassbinder et al., 1990).

Soils that are formed through pedogenesis outside caves and shelters, along with their magnetic constituents, are eroded, tracked, washed or blown and deposited within caves or deep rock shelters. The stratigraphy of these sediments preserves a signature of climate that potentially can be identified by measuring the MS. However, under special or unusual circumstances, other factors may modify these ratios, either outside the cave before erosion, during mineral transport, or inside the cave after deposition. Alteration may be caused by (1) dilution, including the addition of high concentrations of fragmented bone or calcium carbonate pieces created by cryoclastic or anthropogenic processes; (2) dissolution, such as that caused by acidic ground waters; (3) concentration effects other than the production of maghemite during oxidation and pedogenesis, such as the formation of authigenic magnetite by magnetotactic organisms

(Frankel et al., 1979; Torres de Araujo et al., 1986); (4) some differential erosion effects; and (5) concentration effects resulting from chemical changes to iron-containing mineral phases at the expense of already existing iron phases. Most non-pedogenic alteration effects like those discussed above, either occur only locally, or are controlled by climate. We would argue that only climate can have the same effects at the same times over all of southern Europe, as we demonstrate below.

### *Climate Signatures in MSEC Studies in Caves*

We have conducted a number of tests to see if the MS signature is tracking climate. For example, an interesting aspect of some of our MS sections is what appears to be Neo-glacial climate cycles with a duration of approximately 2,500 years like those discussed by Mitchell (1976). Such cycles have also been reported from Greenland ice core data (O'Brien et al. 1995). These cycles were derived from harmonic analysis of MS curves from Konispol Cave, Albania, and Caldeirão Cave, Portugal (Ellwood et al. 1997; 1998). Harmonic analysis of the Early Upper Paleolithic and Solutrean MS data set from Caldeirão Cave shows well-defined 2,500 year cycles within this interval of sediment accumulation.

Sampling for MSEC in conjunction with archaeological excavations provides data sets tied directly to excavation levels, isotopic dates and cultural associations. Because MS variations appear to be controlled primarily by climate, and because the effects of climate are regional, affecting large areas, MS trends identified at one site or in one excavation unit appear at many sites/units within the region. These trends may be modified locally, but in general the variations in MS trends and magnitudes produced by changing climate provide stratigraphic sequences that can be correlated between excavation units that overlap in age. We have used correlated profiles to develop a composite reference section (CRS) of profiles that in turn represent all the MS variations within an area (Ellwood et al., 2001). This CRS can be used for correlation or to estimate paleoclimate. Thus MSEC has the potential to become another independent methodology, alongside conventional methods such as sedimentology and palynology, that can be used to correlate within and between sites by tracing paleoclimatic change. MSEC avoids many drawbacks of other methods, such as high sensitivity to diagenetic changes, poor pollen preservation in caves, ambiguous isotopic ages and the need to acquire oriented or very large samples (MSEC can be performed on 2-10 gm samples).

## **THE MSEC METHOD**

All materials become magnetic when placed in a magnetic field, and MS is an indicator of the strength of this magnetism within a sample. This is very different from remanent magnetism (RM), the intrinsic magnetization that accounts for the magnetic polarity recorded by some materials. In a geoarchaeological context, MS is generally considered an indicator of iron mineral concentration and can be quickly and easily measured on small samples. Essentially, all mineral grains, but especially those containing iron, such as maghemite or magnetite, are «susceptible» to becoming magnetized in the presence of a magnetic field. MS is largely a function of the concentration of the magnetizable material they contain, as well as their composition (mineralogy and grain size or shape) (Nagata, 1961).

Besides its many other qualities, MS has the additional advantages of being quickly and easily measured on small samples using commercially available devices such as balanced coil induction systems (susceptibility bridges), and it is free of problems associated with sample orientation such as those encountered in polarity (reversal) magnetostratigraphy.

We collect continuous sample profiles (each sample covering approximately 2 cm of the vertical section) from excavation units at each site sampled. Each sample is then sieved and the MS for the less-than-1 mm fraction is measured 3 times using the susceptibility bridge in the Paleomagnetism Laboratory at Louisiana State University. The results are calibrated against the U.S. National Bureau of Standards and then interpreted.

### *Protected Environments: Caves and Deep Rock Shelters*

Many archaeological sites are unsuited for MSEC work because they are too complex (Ferrand, 1993) or are affected by physical processes open air sites are not well protected environments (Woodward et al., 1992). From our previous work and the work of others (Woodward and Bailey, 2000), we believe that caves and deep rock shelters are ideal for MS studies of paleoclimate because they are not strongly modified by pedogenic effects after deposition (due to their isolation within caves) and they do record climate as a result of variable rates/intensities of soil formation outside of caves. However, even at open air sites where pedogenesis is active, like those evaluated by Ellwood et al. (1995) in Texas and by Ellwood et al. (1994) in Portugal, useful intrasite correlations were established between excavation units.

### *Holocene MSEC Results from Southeastern Europe*

Due to the problems associated with pedogenesis outside of caves and protected rock shelters (discussed above); we are now looking mainly at protected sites located in caves. We have reported results from a number of sites where MS measurements have been employed at cave sites. These sites include 1) Konispol Cave near the town of Konispol in the Sarandë district of southwestern Albania (A in Figure 1), El Miron Cave (B in Figure 1), two caves from central Portugal (C in Figure 1), and L'Arbreda Cave (D in Figure 1). In addition, here we report the results from Cove de les Cendres (E in Figure 1).

It is now clear that warm climates yield high MS values, if there is sufficient availability of moisture for pedogenesis, and that cold climates yield MS lows. In the case of Konispol Cave, the soils produced outside that cave have been washed and blown into the cave and accumulated. It is also important to note that MSEC data represent relative climate. Relative climate is represented by persistent MS trends toward higher or lower values. One would expect that during an overall, long-term warm period (interglacial) that there would be periods of relative cold. These relative changes in climate are represented in the MSEC data sets.

#### *A Test Using Cova de les Cendres Samples*

As a test of our MSEC work to date we have been investigating the magnetic properties of Cova de les Cendres samples. MSEC data can be a very powerful correlation tool but can't stand alone. It is extremely important that independently derived ages be available for the sections sampled. These data, uncalibrated  $^{14}\text{C}$  dates, are presented for the Cova de les Cendres sections, upper and lower levels, in Figures 2 and 3 (see Bernabeu et al., 1999, for a summary of  $^{14}\text{C}$  dates and their archaeological implication for neolithic levels, Villaverde et al., 1999, for  $^{14}\text{C}$  dates and sequence of paleolithic levels, and Bernabeu, 1989 for a more detailed characterization of neolithic section). Now that an MSEC Composite Reference Section (CRS) has been constructed (Ellwood et al. 2001), with some stratigraphic control from excavations, it is possible to test between site correlations and to resolve dating and other stratigraphic ambiguities. For the purposes of correlation and climatic interpretation, we have included in Figures 2 and 3 bar logs that are simplified representations of the MSEC results. MSEC bar logs are constructed to differentiate between MS highs and lows to divide trend segments. Data of this type can be

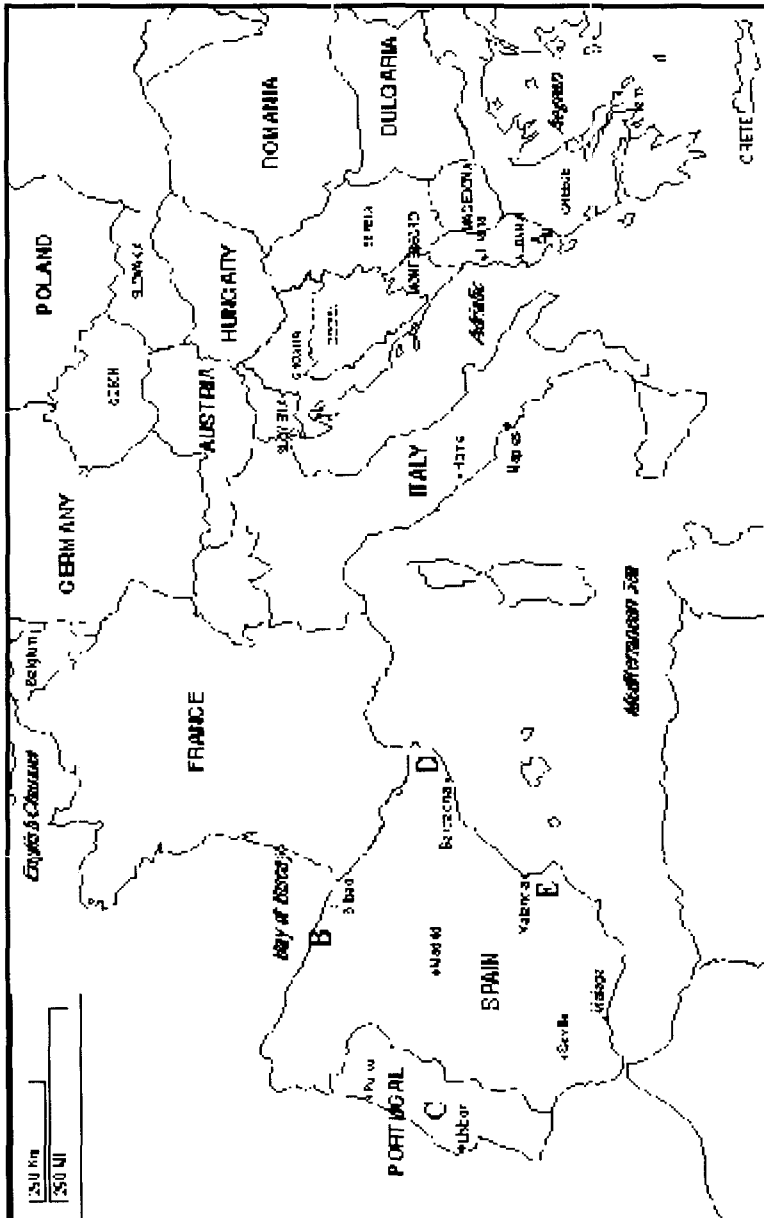


Figure 1. Map of southern Europe with archaeological site locations labeled from A to D, where A = Konispol Cave, Albania; B = El Mirón Cave, Spain; C = Picareiro Cave, Almonda Oliveira Cave and Caldeirão Cave, Portugal; D = L'Arbreda Cave, Spain; E = Cove de les Cendres.

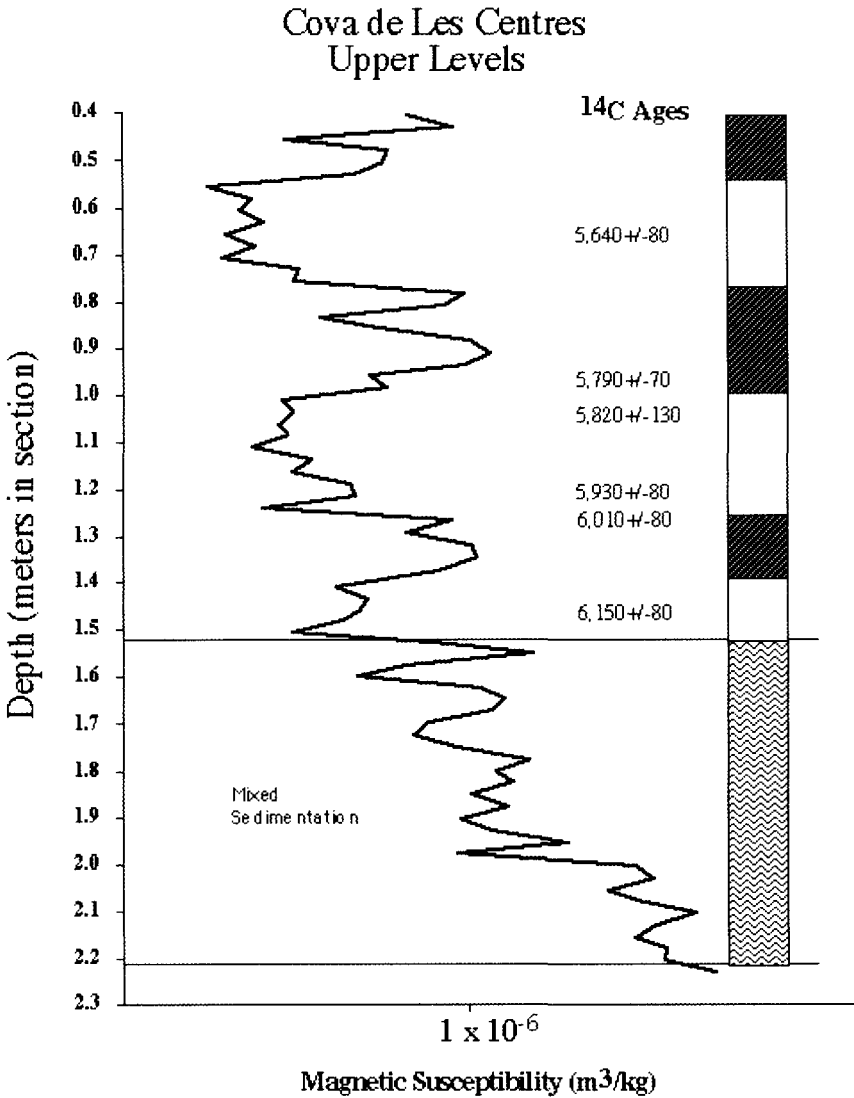


Figure 2. Data from Cove de les Cendres, Upper Section (younger). Curve represents the MS data and the bar logs represent MSEC interpretation. Ages are uncalibrated.



### Cova de les Cendres Lower Levels

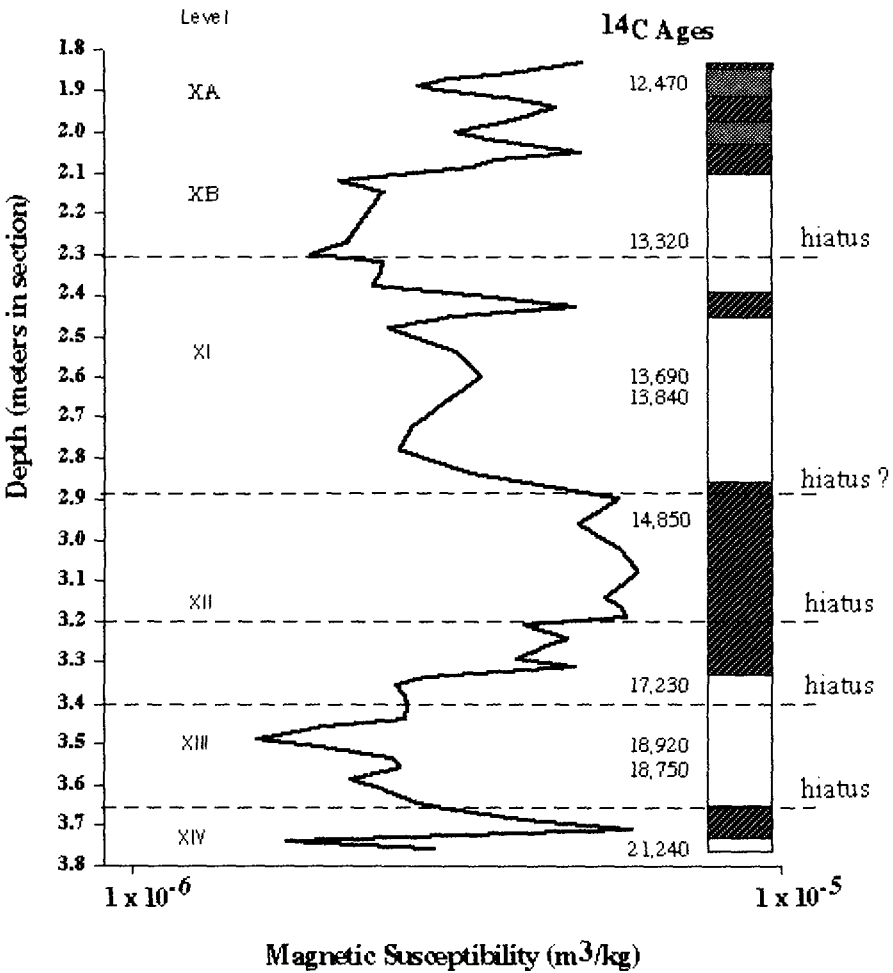


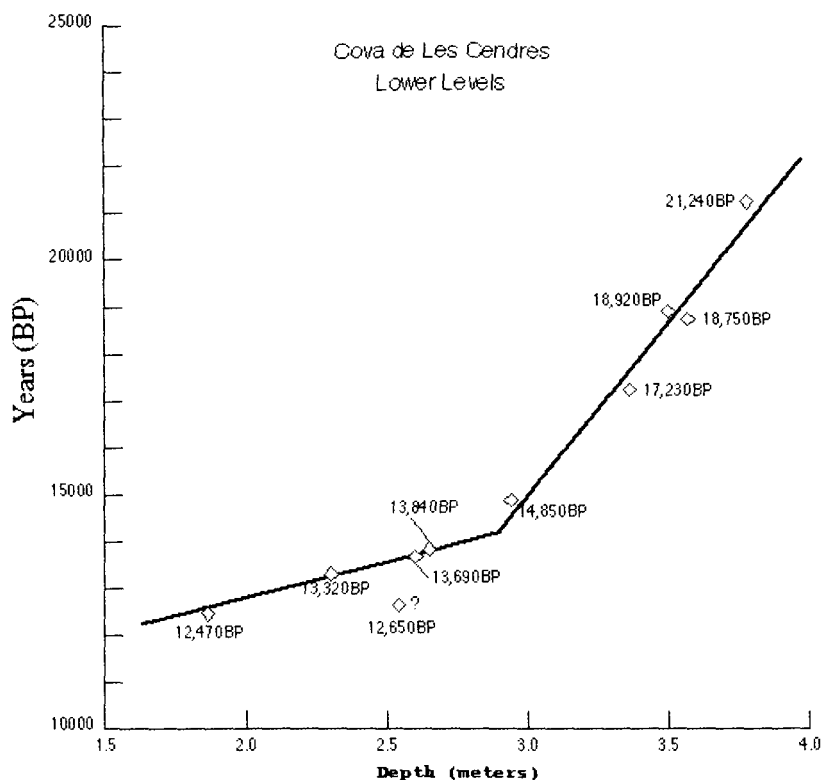
Figure 3. Data from Cove de les Cendres, Lower Section (older). Curve represents the MS data and the bar logs represent MSEC interpretation. Ages are uncalibrated.

compared between excavation units and used in developing a CRS. The filled portions of bar logs in the diagram separate MSEC zones of relative high and low MS values. Hatched areas represent higher MS, interpreted to be times of warmer temperatures, while open areas represent lower MS and cooler times. Zones in the bar logs are differentiated based on midpoints between trends in the raw data toward decreasing or increasing MS.

### *Graphic Correlation*

The Cova de Les Cendres section is divided into upper and lower levels that, based on excavation work and carbon dates, are separated by an interval of mixed sedimentation for which MSEC zones could not be established. To provide correlation horizons tied to the composite cave standard (CCS) that has already been defined (Ellwood et al. 2001), MSEC zones for the Cova de Les Cendres sections are defined in the same manner as for the CCS, and  $^{14}\text{C}$  dates are used to establish time-depth relationships and to fix incremental  $^{14}\text{C}$  ages. For the lower levels, there are sufficient  $^{14}\text{C}$  dates so that a line of correlation (LOC) can be placed through the plot of time-versus-depth points (Figure 4). This LOC acts as a datum through which absolute ages in 1,000 year increments from 13,000 to 21,000 BP are fixed for the Cova de Les Cendres lower levels. An important feature in Figure 3 is the marked decrease in LOC slope above approximately 3 meters, indicating that the sedimentation rate increases significantly above this point.

In the graphic correlation of the lower levels at Cova de Les Cendres, compared to the CCS (Figure 5), the bases and tops of MSEC zones SE-19, 21, and 23 (Fig. 6), and  $^{14}\text{C}$  ages from 13,000 to 21,000 BP plot on the graph. The position of the base and top of SE-23 and the base of SE-21 are consistent with the linear trend established by the  $^{14}\text{C}$  ages. On the other hand, the top of SE-21, and the base and top of SE-19 diverge from the  $^{14}\text{C}$  ages, indicating that these MSEC horizons have been placed incorrectly. These misidentifications may have been caused by two hiatuses within the 2.9 to 3.2 meter lower interval at Cova de Les Cendres. These may have acted to merge SE-19 and 21. To create a closer agreement between these MSEC zones and the  $^{14}\text{C}$  ages, SE-19 is redefined as SE-17 (dashed lines B and C in Figure 5), and the top of SE-21 is redefined as the top of SE-19 (dashed line A in Figure 5). Note that the base of SE-21 requires no change because it is well defined (Figure 5).



*Figure 4. Time-depth graph for the lower interval of the Cova de Les Cendres cave section. Note that the slope of LOC above approximately 3 meters decreases significantly indicating that the rate of sediment accumulation increases above this point.*

### *Southern Europe MSEC Composite Reference Section (CRS)*

In order to make a direct comparison and to establish time lines between caves, we have employed the graphic correlation method (see Shaw, 1964) in building the MSEC CRS for southern Europe (Figure 6). This CRS covers an interval from approximately 3,000 BP to 42,000 BP based on uncalibrated <sup>14</sup>C dates. Within the CRS, 36 MSEC zones are defined representing intervals with relatively high MS values (warm/wet climate). Details on the methods used to construct the CRS can be found in Ellwood et al. (2001).

The MSEC zones represented in the MSEC CRS (Figure 6) are interpreted to reflect climatic trends, warmer/wetter during times

represented by hatched MSEC zones, versus cooler/dryer climates equivalent to open zones in the MSEC CRS. The assigned ages to top and bottom of MSEC events SE-1 to SE-35 in the CRS are given in Table I. As new data become available, for example with the addition of Cova de les Cendres data reported here, the MSEC CRS can be further refined. Thus this CRS continues to improve as a relative dating tool.

*Table I. Uncalibrated  $^{14}\text{C}$  Ages for the MSEC Composite*

MSEC Zones	Top BP	Base BP	Equivalent Warm Climate Phase
SE-1	3,000	3,293	
SE-3	3,634	4,236	
SE-5	4,415	4,756	Atlantic
SE-7	4,919	5,472	Atlantic
SE-9	6,333	6,650	Atlantic
SE-11	7,050	7,550	Atlantic
SE-13	8,800	9,814	Preboreal
SE-15	11,772	11,900	Alleröd
SE-17	13,239	13,805	
SE-19	14,807	15,112	
SE-21	16,234	17,191	Lascaux
SE-23	20,649	21,022	
SE-25	21,583	22,252	
SE-27	27,321	32,047	Arcy/Maisières
SE-29	34,237	35,389	Cottés
SE-31	37,464	39,308	Hengelo
SE-33	40,000	40,922	Hengelo
SE-35	41,383	42,420	

MSEC zones (Figure 6) identified through graphic correlation are given in column 1. Column 2 and 3 are the Top and Bottom dates for each MSEC zone and are derived from the graphic correlation work. Column 4 is the equivalent warm phase summarized by Straus, 1995.

With establishment of the MSEC CRS for southern Europe, a number of simple tests are possible. For example, it is now possible to evaluate the reliability of  $^{14}\text{C}$  dates that are associated with MSEC CRS Zones from individual excavation units where such dates are in question. Also, new MSEC results acquired from individual excavated sections can now be applied directly to the MSEC CRS and used as a relative dating tool, for correlation between sites and for paleoclimatic analysis. However, such comparisons require high-density data sets and isotopic, cultural or biostratigraphic control.

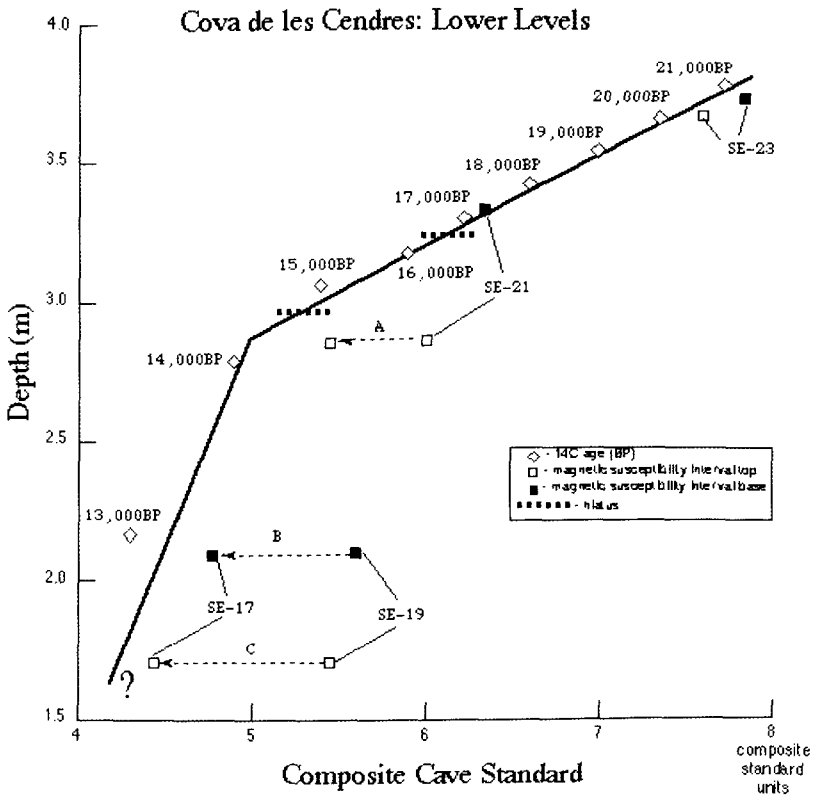


Figure 5. Graphic correlation of the lower interval of the Cova de Les Cendres section. Note that the top of SE-21, and the base and top of SE-19 diverge from the linear trend established by the 14C ages. This problem may result from hiatuses (thick dashed lines in the interval between 14,500 to 17,000 BP) that have acted to merge SE-19 and 21. By redefining SE-19 as SE-17 (dashed line B and C), and the top of SE-21 as the top of SE-19 (dashed line A); a closer agreement is achieved between these MSEC horizons and 14C ages. In addition, the line segment from 14,000 to 13,000 BP is poorly defined, representing error in placement of SE-17.

### Climatic Trends During Upper Paleolithic/Holocene Time

Consistent with the already established MSEC CRS for southern Europe, the data here compliment climate fluctuations from ~42,000 to ~3,000 BP. Toward the end of oxygen isotope Stage 3 (Imbrie et al., 1984), during the period from 42,000 to 37,500 BP, climate was relatively temperate, represented by MSEC zones SE-35 to SE-31. Then there is a change to mixed climates during the period from 37,500 to 25,000 BP,

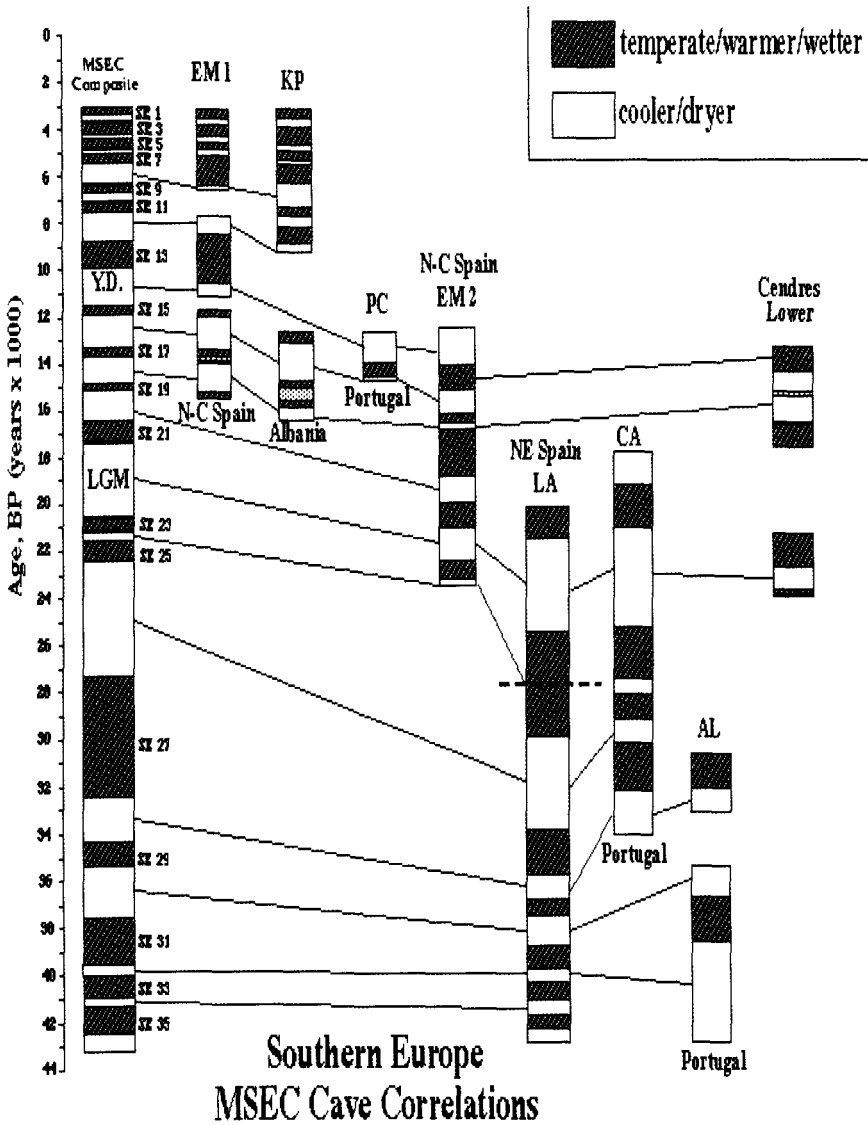


Figure 6. MSEC composite reference section (CRS) for southern Europe for the period ~42,000 to ~3,000 to years BP. Dates defining the CRS are derived from graphic correlation and are presented in Table I. This composite represents a compilation of MSEC bar logs drawn from Konispol Cave (KP), Albania, El Mirón Cave (two sections - EM 1 and EM 2) L'Arbreda Cave (LA), and Cove de les Cendres (CC), Spain; Almonda Oliveira Cave (AL), Caldeirão Cave (CA) and Picareiro Cave (PC), Portugal. Uncalibrated 14C Ages are used.

including MSEC zones SE-29 and SE-27. At ~25,000 BP, and lasting until about 7,500 BP climate became colder, shifting toward the Last Glacial Maximum (LGM). This period of colder climate includes very short temperate MSEC Events SE-25 to SE-13, and included Younger Dryas. The cold period, equivalent to oxygen isotope Stage 2, ended with the start of a trend toward warming during the Holocene that begins with MSEC temperate zone SE-11. During the period between ~23,000 to ~8,000 BP, there were several temperate periods, each of short duration (SE-25 to SE-13; Figure 6). The MSEC record for the Holocene generally represents warming, consistent with other available climatic information from southern Europe.

Examination of Table 1 (Column 4) shows that there is good correspondence between the timing of known warm or temperate periods for Europe and the MSEC CRS. While not perfect, most of the climate zones (summarized by Straus, 1995) are represented, as are the two major cold periods identified during the last 40,000 years. Because the data set is so robust and can be applied to any cave site where sediment is present, it is our belief that the MSEC data set will ultimately yield an extremely fine-scale record of climate for Europe.

Cova de Les Cendres fits well into the MSEC framework and shows good correlation with warm MSEC intervals SE-23 and the base of SE-21 in the lower levels within the cave (Fig. 6). SE-19 and SE-17 are present as well, but these require the presence of a period of non-deposition or erosion that has eliminated cool interval SE-20 between SE-21 and SE-19, as well as some of each of those events. There is archaeological evidence for at least four and possibly five hiatuses within the section (Fig. 3). The hiatus beginning in SE-21 and ending during SE-19, appears to have lasted for ~1,000 years.

#### *Cova de les Cendres: Upper Levels*

For the upper levels at Cova de Les Cendres, there are six <sup>14</sup>C dates that span a relatively short interval from 5,640 to 6,150 BP, a relatively short time span. This time appears to have been a period of relatively fast sediment accumulation, which provides the possibility of higher MSEC resolution. This is possible because individual samples represent relatively short periods of times, estimated at ~10 years from Figure 2, given a time span of ~500 years during which time ~1 m of sediment was deposited and an individual MS sample size representing 2 cm of sediment.

In the graphic correlation of the upper levels at Cova de Les Cendres versus the CCS (Figure 7), the bases and tops of SE-7, and 9 are plotted on the CCS. The age - depth data from Figure 2 when plotted on a time - depth graph exhibit an almost perfect linear relationship. These data indicate that within this interval there are no significant hiatuses or changes in the sediment accumulation rate. Therefore we have used the linear fit through these data to derive two points 5,700, and 6,100 BP <sup>14</sup>C ages, to

### Cova de les Cendres: Upper Levels

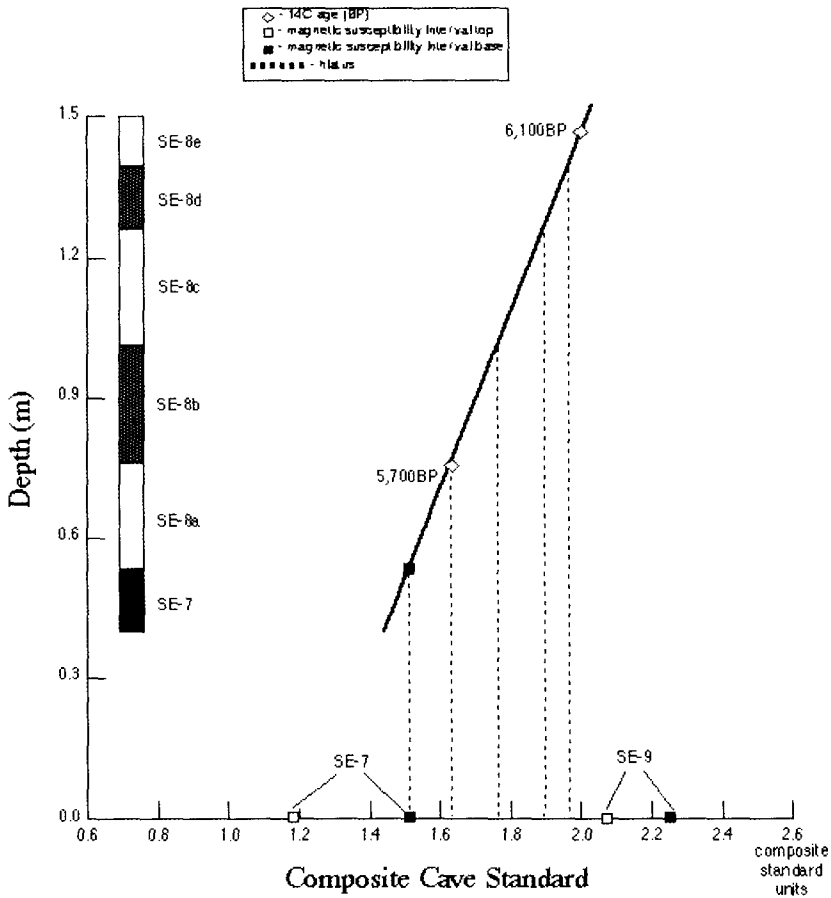


Figure 7. Graphic correlation of the upper interval of the Cova de Les Cendres section. A single, straight LOC is used to fit the scatter of points in this graph suggesting that the upper interval lacks major hiatuses and has a constant sediment accumulation rate.



define the LOC in Figure 7 and these ages plot as points on the graph. It should be noted that only the base of SE-7 falls on the line of correlation, indicating that only part of SE-7 is represented in the upper Cova de les Cendres section (Figure 7). SE-9 falls below the line of correlation.

*Table II. Calibrated <sup>14</sup>C Ages for Upper 20,000 Years of the MSEC Composite*

<i>MSEC Zones</i>	<i>Top BP</i>	<i>Base BP</i>
SE-1	3,179	3,539
SE-3	3,947	4,830
SE-5	5,019	5,533
SE-7	5,625	6,205
SE-9	7,254	7,534
SE-11	7,899	8,370
SE-13	9,823	11,200
SE-15	13,816	13,962
SE-17	15,912	16,565
SE-19	17,718	18,068
SE-21	19,360	20,461

Dates were calibrated using the Radiocarbon calibration program 1999 of Stuiver and Reimer.

These data indicate that the sampled upper section is mainly represented by SE-8, a relatively cool climatic period. The relatively warm intervals present in the data set represented in Figures 2 and 7 appear to be finer scale climate periods that are represented here, either because sedimentation rates are high or they are local climate effects that we do not see elsewhere. However, when we examine the data from the cool SE-8 MSEC interval from Konispol Cave, Albania (Ellwood et al., 2001) we see two short but well-defined warm peaks that appear to correspond with peaks within SE-8 from Cova de les Cendres. Because Konispol sedimentation rates are also relatively high (but not as high as in Upper Levels in Cova de les Cendres) this suggests that these warm peaks are regional events. We have labeled them in Figure 7 as SE-8b and SE-8d, and they appear to represent very short periods of relatively warmer climate, perhaps having a duration of ~100 years each.

## **CONCLUSIONS**

MSEC data from individual cave sedimentary sequences can be compared to the regional MSEC composite reference section already

developed (Ellwood et al., 2001) to yield an independent data set for correlation and relative dating purposes. In addition, it appears from the data presented here, that if sedimentation rates are sufficiently high, we may be able to identify ultra-fine climate variations in MSEC data sets. Our initial results from Cova de les Cendres, when compared to data from Konispol Cave, Albania (Ellwood et al., 1997), indicate that these ultra-fine scale climate variations may be region, and not just local, events.

## ACKNOWLEDGEMENTS

Support for the MSEC research was provided by NSF grant BCS9903172 to Ellwood and Harrold and support for «Tecnología, Economía y Medio Ambiente en la Región Central del Mediterráneo Español entre el Tardiglaciar y el Holoceno medio» research was provided by a grant from Programa Sectorial de Promoción Genral del Conocimiento PB95-1087 to Villaverde and Bernabeu.

## REFERENCES

- BERNABEU, J. (1989): *La tradición cultural de las cerámicas impresas en la zona oriental de la Península ibérica*, Trabajos Varios del SIP, n.º 86.
- BERNABEU, J., VILLAVERDE, V., BADAL, E. and MARTÍNEZ, R. (1999): En torno a la neolitización del Mediterráneo peninsular: valoración de los procesos postdeposicionales de la Cova de les Cendres. *Geoarqueología i Quaternari litoral*. Memorial M.P. Fumanal, 69-81.
- ELLWOOD, B.B., HARROLD, F.B., BENOIST, S.L., STRAUS, L.G., GONZALEZ-MORALES, M., PETRUSO, K., BICHO, N.F., ZILHÃO, Z., and SOLER, N., (2001): Paleoclimate and Intersite Correlations from Late Pleistocene/Holocene Cave Sites: Results from Southern Europe, *Geoarchaeology*, in press.
- ELLWOOD, B.B., HARROLD, F.B., & MARKS, A.E. (1994): Site identification and correlation using geoarchaeological methods at the Cabeço do Porto Marinho (CPM) locality, Rio Maior, Portugal, *Journal of Archaeological Science*, 21, 779-784.
- ELLWOOD, B. B., HROUDA, F., & WAGNER, J. J. (1988): Symposia on magnetic fabrics: Physics of the Earth and Planetary Interiors, 51, p. 249-392.
- ELLWOOD, B.B., PETER, D.E., BALSAM, W., & SCHIEBER, J. (1995): Magnetic and Geochemical Variations as Indicators of Paleoclimate and Archaeological Site Evolution: Examples from 41TR68, Fort Worth, Texas, *Journal of Archaeological Science*, 22, 409-415.
- ELLWOOD, B.B., PETRUSO, K.M., & HARROLD, F.B. (1996): The Utility of Magnetic Susceptibility for Detecting Paleoclimatic Trends and as a Stratigraphic Correlation Tool: An Example from Konispol Cave Sediments, SW Albania, *Journal of Field Archaeology*, 23, 263-271.
- ELLWOOD, B.B., PETRUSO, K.M., HARROLD, F.B., & SCHULDENREIN, J. (1997): High-Resolution Paleoclimatic Trends for the Holocene Identified Using Magnetic Susceptibility Data from Archaeological Excavations in Caves, *Journal of Archaeological Sciences*, 24, 569-573.
- ELLWOOD, B.B., ZILHÃO, J., HARROLD, F.B., BALSAM, W., BURKART, B., LONG, G.J., DEBÉNATH, A., & BOUZOUGGAR, A. (1998): Identification of the Last Glacial Maximum in the Upper Paleolithic of Portugal using magnetic susceptibility measurements of Caldeirão Cave sediments, *Geoarchaeology*, 13, 55-71.

- FASSBINDER, J.W.E., STANJEK, H., & VALI, H. (1990): Occurrence of magnetic bacteria in soils, *Nature*, 343, 161-163.
- FERRAND, W.R. (1993): Discontinuity in the stratigraphic record: snapshots from Franchthi Cave. In: Goldberg, P., Nas, D.T., and Petraglia, M.D., Eds., *Formation Processes in Archaeological Context, Monographs in World Archaeology, No. 17*, Prehistory Press, Madison Wisconsin, 85-96.
- FRANKEL, R.B., BLAKEMORE, R.P., & WOLFE, R.S. (1979): Magnetite in Freshwater Magnetotactic Bacteria. *Science* 203, 1355-1356.
- MAHER, B.A. & TAYLOR, R.M. (1989): Formation of ultrafine-grained magnetite in soils, *Nature*, 336, 368-370.
- MITCHELL, J.M. Jr. (1976): An overview of climatic variability and its causal mechanisms, *Quaternary Research*, 6, 481-493.
- MULLENS, C.E. (1977): Magnetic susceptibility of the soil and its significance in soil science - a review, *Journal of Soil Science*, 28, 223-246.
- NAGATA, T. (1961): *Rock Magnetism*, Maruzen Company, Ltd., Tokyo, 350 pp.
- O'BRIEN, S.R., MAYEWSKI, P.A., MEEKER, L.D., MEESE, D.A., TWICKLER, M.S., & WHITLOW, S.I. (1995): Complexity of Holocene climate as reconstructed from a Greenland ice core, *Science*, 270, 1962-1964.
- SHAW, A.B. (1964): *Time in Stratigraphy*, McGraw Hill, New York, 365 pp.
- SINGER, M.J., & FINE, P. (1989): Pedogenic factors affecting magnetic susceptibility of northern California soils, *Soil Science Society of America Journal*, 53, 1119-1127.
- STANJEK, H., FASSBINDER, J.W.E., VALI, H., WAGELE, H. & GRAF, W. (1994): Evidence of biogenic greigite (ferrimagnetic Fe<sub>3</sub>S<sub>4</sub>) in soil, *European Journal of Soil Science*, 45, 97-103.
- STRAUS, L.G. (1995): The Upper Paleolithic of Europe: An Overview, *Evolutionary Anthropology*, 4, 4-16.
- TITE, M.S., & LININGTON, R.E. (1975): Effect of Climate on the Magnetic Susceptibility of Soils, *Nature*, 256, 565 - 566.
- TORRES DE ARAUJO, F.F., PIRES, M.A., FRANKEL, R.B., & BICUDO, C.E.M. (1986): Magnetite and Magnetotaxis in Algae. *Biophysical Journal* 50, 375-378.
- VILLAVARDE, V., MARTÍNEZ, R., BADAL, E., GARCÍA, R. And MENARGUES, J. (1999): El Paleolítico superior de la Cova de les Cendres (Teulada-Moraira, Alicante). Datos proporcionados por el sondeo efectuado en los cuadros A/B-17. *Archivo de Prehistoria Levantina*, XXIII, 9-65.
- WOODWARD, J.C. & BAILEY, G.N. (2000): 27. Sediment sources and terminal Pleistocene geomorphological processes recorded in rockshelter sequences in North-west Greece, In., *Tracers in Geomorphology*, Foster, I.D.L., Ed., John Wiley & Sons, Ltd., London, 521-550.
- WOODWARD, J.C., LEWIN, J., & MACKLIN, M.G. (1992): Alluvial sediment sources in a glaciated catchment: the Voidomatis Basin, northwest Greece, *Earth Surface Processes and Landforms*, 17, 205-216.

