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AN OVERVIEW OF THE QUATERNARY CONTINENTAL STRATIGRAPHIC UNITS BASED ON BIOLOGICAL AND CLIMATIC EVENTS IN ITALY

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ABSTRACT
A short review about Quaternary continental stratigraphic units based on biological and climatic events is provided, with several examples taken from Italy. The potential of biochronological and biostratigraphical units is discussed. The suitability of climate events and of composite regional units in continental stratigraphy is also stressed, although a consistent definition and formal status of the latter units are not yet available.

RIASSUNTO
Le unità stratigrafiche basate su eventi biologici e climatici sono di largo uso nel Quaternario continentale, ma il loro status non è ben definito da accordi internazionali. Nel presente lavoro si evidenzia il significato e l'utilità delle unità biocronologiche, biostratigrafiche, climatostratigrafiche e cronostratigrafiche e si auspica che venga mantenuta una rigorosa distinzione nel loro impiego, prendendo spunto da vari esempi in Italia. Viene posto l'accento sull'indipendenza delle unità biocronologiche continentali dalle biozone stratigrafiche. Queste ultime sono applicabili alla distribuzione stratigrafica di microfossili (polline, diatomee) e di piccoli invertebrati, ma non è il caso dei grossi mammiferi. Le unità climatostratigrafiche riguardano sia eventi a scala globale, sia regionale o locale; in ogni caso sono diacroniche e non danno luogo a correlazioni di significato strettamente cronostratigrafico. La mancanza di una chiara distinzione tra unità biostratigrafiche e climatostratigrafiche ha creato confusione nella terminologia riguardante la parte terminale del Pleistocene superiore e dell'Olocene. Il significato delle unità in uso in questo intervallo viene discusso in un'apposita tabella. Viene infine considerata la natura composita di alcune unità in uso nel Quaternario continentale a scala regionale in Europa occidentale, le quali risultano dalla combinazione di tutti i dati disponibili di interesse stratigrafico e cronologico. L'impiego con un significato cronostratigrafico di tali unità non dovrebbe essere confuso con la loro natura e definizione.

Key words: Quaternary biostratigraphy, Biochronology, Pollen zonation, Climatostratigraphy.

Parole chiave: .

1. INTRODUCTION

Reconstructing the Quaternary stratigraphy in continental environments is a difficult task because of the low degree of succession continuity and of the scattered paleontological documentation. Although biological and climatic events help understanding sedimentary sequences and mapped geological units, the usage of biochronology, biostratigraphy, climatostratigraphy and composite regional stratigraphy is still limited. This paper provides a brief review to the potential of these units, with several examples from Italy. A Late Pleistocene and Holocene chrono- and climatostratigraphic subdivision of continental Italy and part of Europe is also presented.

2. BIOCHRONOLOGY, BIOCHRONOSTRATIGRAPHY AND BIOSTRATIGRAPHY

Fossiliferous continental deposits formed in a regime of virtually continuous sedimentation can be found in deep lacustrine environments, but they record relatively short time periods (10^3 – 10^4 years) compared to marine successions. This obstacle may be partially overcome by applying biochronological criteria. <u>Biochronology</u> is the subdivision of geological time by means of biological events, i.e. the evolution of the organisms with respect to time and other paleobiological events, which do not imply consideration of the stratigraphic relationships among the rocks in which the fossils are included (Berggren & Van Couvering, 1978; Raffi & Serpagli, 1993, Tab. 1). Biochrons can be defined thanks to the theoretical base provided by irreversible organic evolution, and by other paleobiological events (e.g. immigration, dispersal, emigration, and extinction). However, often the continental faunal units used in Italy miss a reference to any body of rocks, or, in other terms, body of rocks including faunal assemblages have been not preserved after the fossil collection. In these conditions, it may be impossible to describe biostratigraphic units, and only biochronologic or biochronostratigraphic unit can be conceived[1] . The concepts of mammal continental biochronology were developed by Lindsay and Tedford (1990), Fejfar & Heinrich (1990) and Walsh (1998). A Quaternary biochronological scheme of the Italian mammal and mollusc faunal complexes is well established (Gliozzi *et al.*, 1997; Kotzakis, this issue). The interpretational approach provided by biochronology is also inherent the characterization of <u>floristic com-</u>

[1] **Biochronostratigraphic units** are "the sets of rock formed during biochrons, without reference to any particular stratigraphic section" (Walsh, 1998). **Biostratigraphic units** are instead "bodies of rock strata that are defined or characterized on the basis of their contained fossils" (ICS, 1994, p. 53).

Table 1 - The stratigraphic categories currently used in Quaternary sciences. The table includes units formally defined in the International Code of Stratigraphy (Salvador, 1994) and other categories that, despite not yet formally defined by ICS, are of importance for Quaternary stratigraphy and are of common usage. The relevant references (only for units not included in ICS) are here reported: 1 - Cushing, 1967; Birks & Gordon, 1985; Tzedakis, 1994; 2 - Kerney et al., 1980; 3 - De Giuli et al., 1986; 4 - Fejfar & Heinrich, 1990; Lindsay & Tedford, 1990; Walsh, 1998; 5 - De Giuli et al., 1983; 6 - Mai & Walther, 1978; 7 - Lowe & Walker, 1997; 8 - Walker et al., 1999; 9 - Johnson et al., 1997; 10 - Zagwijn, 1992. The term “composite regional units” is used to refer “regional Stages” of the Dutch stratigraphy. This terminological problem is discussed in the text.

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Summary of categories used
in the continental Quaternary stratigraphy
(non-referred units are from Salvador, 1994)

(*) Mappable units; (+) Stratotype sections applicable

1. CHRONOLOGY

Chronostratigraphy (*) (+)
Eonothem
Erathem
System
Series
Stage
Substage
Chronozone

Equivalent Geochronologic Units
Eon
Era (Cenozoic)
Period (Quaternary)
Epoch (Pleistocene)
Age
Subage
Chron

2. ROCK PROPERTIES

Lithostratigraphy (*) (+)
Group
Formation
Membre
Stratum

Pedostratigraphy (*)

Mineralogy (*) (+)
Heavy mineral assemblages

Magnetostratigraphy (+)
Polarity zone

Isotopic stratigraphy (+)
$\delta^{18}O$ stages from sea records
(MIS = Marine Isotopic Stages)
$\delta^{18}O$ from polar ice (GS / GI)
Termination

Chemiostratigraphy

3. FOSSIL CONTENT

Biostratigraphy (+)
Pollen superzone[1]
Pollen zone
Other biozones and ecozones[2] (based on diatoms, cyanobacteria, green algae, Ostracods, Molluscs, etc.)

Biochronostratigraphy and Biochronology
Biochronological events[3]
Land Mammal Ages[4]
Faunal Units[5]
Local Faunas[5]
Floral Complexes[6]
Local Floras[6]
Human cultural chronology

4. COMPOSITE AND INTERPRETATIONAL STRATIGRAPHIC CATEGORIES (ONLY 4.B AND 4.E ARE DETAILED HERE)

4.A. CYCLOSTRATIGRAPHY (*) (+)

4.B. EVENT DIACHRONIC STRATIGRAPHY

Event (Whittaker et al., 1991)

Based on climatic events inferred by stratigraphic pattern [Climatostratigraphy (+)] and other events:
Geologic-climatic (geoclimatic) units[7]
Global interglacial, Global glaciation[7]
Stadial, Interstadial Episodes and Sub-episodes (mostly at regional scale)
GI/GS (Greenland Stadial / Interstadial Episodes and Subepisodes)8

Based on boundaries of referent deposits from where events are inferred (*)
Rock diachronic Event Units9
Episode
Subepisode
Phase

4.C. UNCONFORMITY BOUNDED STRATIGRAPHIC UNITS

4.D. SEQUENCE STRATIGRAPHY

4.E. REGIONAL COMPOSITE STRATIGRAPHY (*) (+)

Composite regional stage[10]
A combination of the above mentioned properties (e.g. Paleomagnetic Polarity, Lithostratigraphy, Susceptibility log, Radiometric dating, Pollen stages succession, Climatostratigraphic succession) considered at regional scale and boundary-defined.

plexes, first defined in the lowlands of Germany (Mai & Walther, 1978) and recently applied to the continental carpofloral assemblages of the western Po Plain (Martinetto, 1995).

Considering the Italian continental paleobiological record, only the distribution of some microfossil, e.g. pollen and diatoms, and of small invertebrates (Ostracods, Chironomids), matches the requirements to establish biostratigraphic units. There are only a few examples of continental biostratigraphy in Italy. Several paleoecological investigations have proposed a local biozonation, based on the succession of biotic assemblages at a single lacustrine or palustrine small basin. So far there is detailed local biozonation back to 14 kyr BP at the southern Alpine foothill (Schneider, 1978; Wick, 1996), in Central Alps (Tinner, 1998; Pini, 2002), in the central Italian peninsula (Lowe, 1992; Brugiapaglia & de Beaulieu, 1995; Lowe *et al*., 1996) and in central Sicily (Sadori & Narcisi, 2001). The pollen zonation from the Monticchio maar lake (southern Apennines) and from the Latium extends to the last 100 kyr BP (Magri, 1999; Magri & Sadori, 1999; Allen & Huntley, 2000). One site is zoned back to about 250 kyr BP (Valle di Castiglione: Follieri *et al*., 1988). Detailed pollen zonation is also available for the Middle Pleistocene lacustrine record of Vallo di Diano (Russo Ermolli, 1994), from part of the Early Pleistocene lacustrine sequence of Leffe in the Lombardian Pre-Alps (Ravazzi & Rossignol Strick, 1995; Ravazzi & Moscariello, 1998) and from the late Early Pleistocene Colle Curti and Cesi basin sequence (Bertini, 2000).

The development of regional pollen zones applies to biogeographically homogeneous regions, which are provided with several pollen records. Although each site is characterized by a peculiar vegetation development (shown by the succession of local pollen zones spanning an entire warm or cold phase: this is the concept of pollen assemblage superzone, proposed by Tzedakis, 1994), a comparative inspection of pollen curves shows that different sites have in common a similar background pollen, after eliminating local plants from the pollen sum. This is the case of Latium maar lakes, where the main changes observed in the five long pollen records available have been correlated (Follieri *et al*., 1989). A quantitative analysis by numerical methods (Sugita 1994) can help defining the biogeographical limits of a regional pollen zone. Regional pollen zones are commonly time-transgressive (Lowe & Walker, 1997); this is partially due to migration time lags (10^2 kilometers per 10^3 years). However, once the migration pattern is known and well dated, the time of immigration and / or expansion at a given site by a good pollen producer may be a precise biostratigraphic marker (e.g. the Holocene migration history of Picea, Ravazzi, 2002).

3. EVENT STRATIGRAPHY AND CLIMATOSTRATIGRAPHY

Climatostratigraphy (the modern development of geoclimatic stratigraphy) is a type of “event diachronic” stratigraphy based on interpreted climate features from evidence in the rock/sediment record (see Lowe & Walker, 1997). Events are short-term phenomena that leave some trace in the geological record (e.g. volcanic eruptions, sea level changes, etc.). As noted by Walker *et al*. (1999), "it is primarily the events and not the boundaries between the events that are specifically designated" (by climatostratigraphic inferences). Furthermore, climatostratigraphy "acknowledges the fact that the stratigraphic boundaries marking the onset and ending of a climatic event may well be diachronous (.....)". Climatostratigraphic units are best derived by a combination of different stratigraphical categories, such as lithological, biological, isotopic (Walker *et al*., 1999), and UBSU units used in sequence stratigraphy (Miall, 1997).

Whenever emphasis is on globally recognized climatic-events, climatostratigraphic subdivisions may concern the whole Earth, such as global glaciations, interglacials and the interglacial-glacial cycle. Local climatostratigraphic units may represent events recorded by relevant deposits, for instance at the scale of a basin catchement (e.g. high-intensity rain triggering catastrophic floods), or of a climatic province (e.g. lake level changes, etc.), or of a whole mountain chain (e.g. local glaciation). Climatic events which occurred at regional scale, together with other derivate types of event stratigraphic units, such as volcanic eruptions, are widely used in Italy (Narcisi & Vezzoli, 1999) and provide a powerful method for marine / continental correlations. For instance, the beginning of the late glacial interstadial (Tab. 2) has been recognized in maar deposits from the Italian peninsula as well as in marine sediments from the Adriatic sea. Inter-regional and marine / continental correlation has been possible thanks to the background arboreal pollen signal, which shows an abrupt shift at 12.4 ka ^{14}C BP (Lowe *et al*., 1996). This pollen signal has been compared with other paleoclimatic proxies (geochemistry, rock-magnetism, isotopes, diatoms, other algae, investebrate fossil remains), for a multidisciplinary evaluation of the climatic event triggering the observed physical and biological changes (Guilizzoni & Oldfield, 1996). The climatic events are commonly very close to the boundaries of the biostratigraphic subdivisions from where events are inferred. The International Stratigraphic Guide (Salvador, 1994) misses to consider climatostratigraphy as a basic stratigraphic category of common use. The present author believes that a rigorous distinction between biostratigraphic and climatostratigraphic units needs to be maintained (on this problem see Turner, 2002 discussing the status of the Eemian interglacial). An effort to add precision to the terminology used in different branches of stratigraphy is made in Tab. 2 and 3.

4. COMPOSITE REGIONAL UNITS

Several Quaternary stratigraphers from Central Europe acknowledges the use of continental “stages” (Gibbard *et al*., 1991; Zagwijn, 1998). From the paleoclimatological point of view, some of them are “complex stages” (Zagwijn, 1992, p. 585). These units (Tab. 1b) derive from a combination of all available stratigraphic (lithologic, UBSU, magnetic, biologic and climatic) and chronological (geocronometric, biochronological) data. The paleoclimatic complexity of such units is not the only defining characteristics, and therefore I would suggest to refer them as composite regional units. Because they are based on diachronic-type stratigraphic units

Tab. 2 - Framework of Late Pleistocene chronologic and climatostratigraphic reference units used in Western-Central Europe (column climatostratigraphy dealing with the Alps only) and detail of local units applicable to selected regions. ALGM = Alpine Last Glacial Maximum. The age of Northern Germany and Netherlands interstadials (Oerel, Glinde, Moershoofd, Hengelo and Denekamp) is from Behre & van der Plicht (1992), calibrated with the method by Bard et al. (1998). Alpine deglaciation and the late-glacial interstadial may be partially coeval. The term Neoglaciation is from Porter & Denton (1967).

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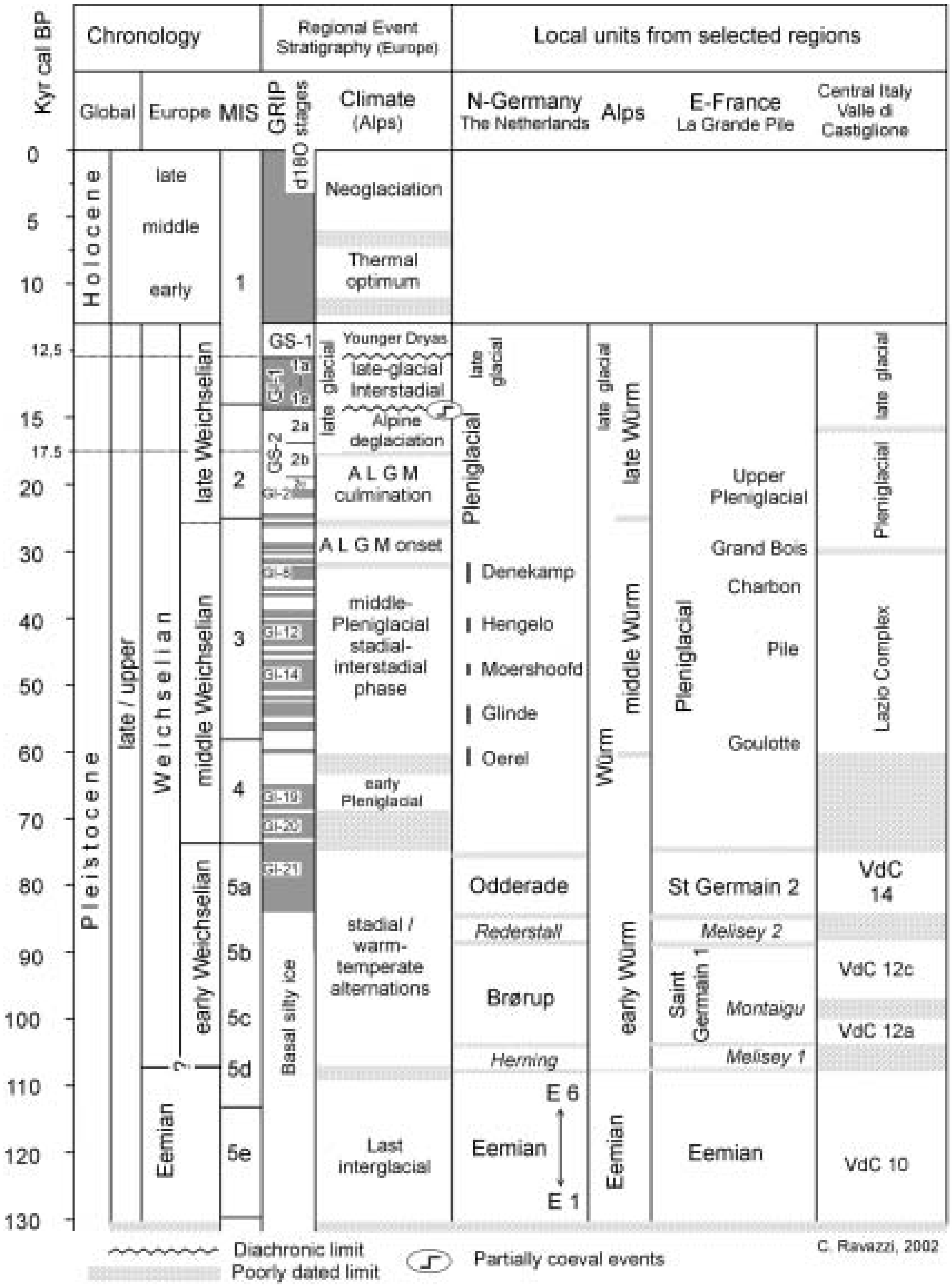

Tab. 3 - Late glacial and Holocene chronostratigraphy / geochronology and climatostratigraphic units (from Orombelli & Ravazzi, 1996, modified and updated). Chronozones are framed by conventional ^{14}C ages BP. The late glacial is subdivided by using climatostratigraphic criteria. This is because the late glacial is characterized by sharp climatic changes which have been recognized either in terrestrial biological records, either in ice and in marine records, but these climatostratigraphic transitions do not fit the boundaries of the relevant chronozones proposed by Mangerud et al. (1974). Consequently, these late glacial chronozones miss any practical interest. Holocene chronozones are provisory maintained here, waiting for further international agreements. Note that the Last Glacial Maximum in the Italian Alps ends about 15 ka ^{14}C BP, well before than in Central and Northern Europe. The earliest interval of the Alpine late glacial, or, in other terms, the time interval between the beginning of the Alpine deglaciation and the late glacial interstadial is poorly defined in stratigraphic terms.
(* 1) The subdivisions early, middle and late Holocene are informal, with boundaries at ca 7000 and 3000 BP.
(* 2) The calendar ^{14}C age BP has been calibrated with the program CALIB 4.0 elaborated by Stuiver and Reimer (1998). The calibrated ages are reported as one Sigma time intervals obtained using a standard deviation of ± 50 yr on the conventional age.
(* 3) The framing of the "Holocene thermal optimum" between about 9 and 5 kyr ^{14}C BP is based on: i) the $\delta^{18}O$ curve from the Renland ice core (Larsen et al., 1995); ii) the record of Alpine glacier contraction durin the early-middle Holocene (Hormes et al., 2001); iii) the paleoecological record of treeline oscillation in the Alps (Wick & Tinner, 1997). This concept of the Holocene thermal optimum is different from the hypsithermal (Porter, 1981), used in a previous version of this scheme (Orombelli & Ravazzi, 1996).
(* 4) The Younger Dryas is here taken as a climatostratigraphic unit. L.I.A. = Little Ice Age. Dashed lines indicate large-scale diachronic boundaries.
(* 5) A substantial increase of climatic humidity in the Alps does not fit this Boreal / Atlantic chronozone boundary but occurred later, about 7.3 Ka ^{14}C BP, i.e. about 8.2 Ka cal BP (Tinner & Lotter, 2001; Pini, 2002).
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Series / Epoch	Stage / Age	INFORMAL SUBDIVISIONS (*1)	climato-stratigraphic subdivisions (*1)	CHRONO ZONES (Holocene only)	Conventional age ^{14}C yr BP (Mangerud et al., 1974, 82; Litt et al., 2001)	Calibrated age cal ^{14}C BP (*2) (Stuiver et al., 1998)	Varve chronology from German and Polish lakes (Litt et al., 2001)
HOLOCENE		LATE	100 L.I.A. 500; NEOGLACIATION	Subatlantic			
					2500	2728-2476	
		MIDDLE	c. 5000 BP	Subboreal			
					5000	**5728** 5657-5828	
			c. 5300 BP; THERMAL OPTIMUM	Atlantic			
					8000 (* 5)	8776-9004	
		EARLY		Boreal			
			(* 3)		9000	**10.189** 9944 - 10.004	
			c. 9000 BP	Preboreal			
					10.000	11.268 - 11.553	11.480-11.590
PLEISTOCENE	Würm = Weichselian	Late glacial	*Younger Dryas (* 4)*				
					c. 10.700	**12.840** 12.896 - 12.644	12.650-12.680
			late glacial interstadial				
					c. 12.300	**14.289** 15.416 - 14.101	14.450
			"early late glacial"				
					c. 15.500		
			Last Glacial Maximum (Alps)				

(such as climato- or biostratigraphic units) they are not chronostratigraphic units (not a Stage by definition). However, composite regional units are also intended to provide a chronostratigraphical reference for biogeographically circumstantied regions, hence the term "stage" (which implies a chronostratigraphic unit) has been used with reference to rocks formed during the relevant time interval (Gibbard *et al.*, 1991; Zagwijn, 1992). The usage of a composite regional stratigraphy in continental regions is not formalized by the International Stratigraphic Code currently in use (Salvador, 1994), and its chronostratigraphic value is still a matter of debate (Gibbard & West, 2000). Composite regional units are also characterized by a stratotype. For instance, an Eemian stratotype was provided by van der Heide and Zagwijn (1967); see Turner (2002), for a review. Moreover, reference sections and boundaries or boreholes may be designated, such as the Amsterdam borehole for the Eemian (van Leeuwen *et al*., 2000). The designation of stratotypes and / or reference sections for continental units is mentioned by the International Stratigraphic Code currently in use (ICS, 1994, p. 77). The present author believes reference sections to be necessary for any further study. This procedure is expecially fruitful in case that bioprovinces are partially cohincident with sedimentary basins, a situation which may apply to the Quaternary evolution of the Apenninic intermontane basins and of the Po Plain. Unfortunately, so far there are no proposals for composite regional units in Italy.

5. CONCLUSION

A consistent definition and formal status of continental stratigraphic units based on biological and climatic events is not yet available in the official agreements of IUGS and INQUA. This paper has emphasized the importance to maintain rigorous distinction among biochronologic, biostratigraphic, climatostratigraphic and chronostratigraphic units.

The marked geological, environmental and climatic diversity affecting both the Alpine and the Mediterranean regions hampers correlation based on biological and climatic events. Hope is placed in a multidisciplinary characterization of bioprovinces and of their relation to the major sedimentary archives of past environmental change.

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