STATE OF THE ART ABOUT THE TORTONIAN/MESSINIAN BOUNDARY

by

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Knowledges concerning the correlations of the late Tortonian to early Messinian time lap as well as the suggestion of a possible Messinian GSSP have considerably increased during the last few years (Tab. 1). Advances have occurred for all major correlation tools (radiocronometry, magnetostratigraphy, cyclostratigraphy and astrochronometry), both at the general level (new calibrations of oceanic magnetic anomalies) and in the study of continuous sections on land and in the deep sea.

Radiochronometry

In the early '60, the chronometric estimate of the T/M boundary had a major jump from 13 Ma (Kulp 1960, 1961 based on radiometric datings of the north American "Hemphillian" mammal faunas poorly correlated with the regional Paratethyan Pontian stage) to about 7 Ma (PTS 1964, based on the intrusion age of the Elba granite according to Eberhardt and Ferrara 1962). Until recently, the same estimate fluctuated from 5.6 to 6.5 around a modal figure of about 6.2 Ma. The first direct K/Ar dating of many latest Tortonian tephras intercalated in newly discovered, continuous, biostratigraphically well studied sections of the Northern Apennines suggested an extrapolated age of 7.26±0.1 Ma for the T/M boundary related to the FAD of the *G. conomiozea* Zone (Vai et al., 1992, 1993). Ages consistent with the one above have also been obtained from correlative tephras in the central Apennine (A. Deino in Coccioni et al., 1992, and Cosentino, (pers. Com. 1994). Ar/Ar datings of the same latest Tortonian and of new early Messinian tephras from the Northern Apennines have bracketed the T/M boundary quite close to 7.15 Ma (Laurenzi et al., 1995). Almost the same results have been obtained in other sections of the Northern Apennines (Odin et al., 1995). Based on these results, the recent Geological Tima Scale by Odin (1994) suggests an age of 7.1 Ma with approximation of ±0.3 for the Messinian base. Also the first preliminary results from Ar/Ar dating of some ash beds intercalated in the Metochia section on Gadvos and in the Faneromeni and Kastelli sections in Crete (Hilgen pers. com. 1995) seems to be consistent with the above results.

Magnetostratigraphy

The new calibrations of the oceanic magnetic anomalies (Cande & Kent, 1992, 1995) have considerably icreased the ages of all polarity units in the Pleistocene to late Neogene in comparison with the figures of the previous calibration (Berggren et al., 1985). The interpolated age of the T/M boundary would be 6.925 following the scale of Cande & Kent (1992). The revised version of the geomagnetic polarity time scale according to Baksi (1993) and Cande & Kent (1995) suggest an interpolated age of 7.03 and 7.11 Ma respectively for the same T/M boundary. On land, excellent magnetostratigraphic results have been obtained in the Crete sections (Krijgsman et al., 1994; Krijgsman et al, 1995, MIOMAR vol.). There, the T/M boundary (related to the First Regular Occurrence of the *G. conomiozea* group) is contained within the short reversed subchron 3Br.1r. These revised and much more detailed studies have considerably improved the previous magnetostratigraphic interpretation of the Crete sections, from which a calibration of the T/M boundary at 5.6 Ma was first derived (Langereis, 1984).

Useful magnetostratigraphic results have also been obtained in the lower part of the Monte Tondo section (Northern Apennines) by Calieri et al. (1992) and by Negri & Vigliotti (1995). Also here, the T/M boundary (FAD of *conomiozea*) is contained within a reversed interval, as in most of the sections on land and in the deep sea studied so far. Few exceptions are Leg 107 in the Mediterranean (Channel et al., 1990; Glaçon et al., 1990) and the Atlantic Morocco (Benson & Rakic-El Bied, 1991: Hodell et al., 1994) due to uncertain polarity assessment and different criteria of establishing species range. Less convincing is the stratigraphic and magnetostratigraphic interpretation of the Sorbas section (Gauthier et al., 1994), where the planktic *G.conomiozea* first occurrence (again in Chron 3Bn) might be controlled by the sharp facies jump from littoral bioclastic limestone and sand to bathyal marls.

Recently, a very detailed palaeomagnetic resampling of the Monte del Casino section (Northern Apennines), containing most of the tephras dated by Vai et al., (1992, 1993) and Laurenzi et al. (1995), has been performed by Hilgen, Lourens and Krijgsman. The study is in progress.

Cyclostratigraphy

Very detailed measurements of magnetic susceptibility have proven to be the most reliable tool in detecting lithoc-ycles which can be missed by visual inspection. Alternating calcium carbonate- and/or organic matter-rich and poor couplets (light and dark coloured mudstones) are impressively developed in many T/M sections especially in the Mediterranean. Many cyclostratigraphic researches, including field surveying of cycles, isotope analysis of foraminiferal tests, geochemical fluctuations, and rythmic distribution of climatically sensitive foraminifera species are in progress, in press or published, according to the followin partial list:

1) Dinelli & Tateo (1993), geochemical and mineralogical data, Northern Apennines sections; 2) Calieri (1992): planktic foraminifera cyclycity, N. Apennines sections; 3) Hodell et al. (1994): benthic foraminifera stable isotope stages, on land Moroccan core; 4) Krijgsman et al. (1994):Crete sections; 5) Vai (1995): N. Apennines sections; 6) Ferretti & Terzi: stable isotope and organic matter, N. Apennines sections; 7) Sprovieri: foraminifera palaeoclimatical cyclicity, Sicily sections.

Astrochronometry

Astronomical time scales are quite firmly established for the last 6 Ma or so (Shackleton et al., 1990, 1995; Hilgen, 1991a, 1991b; Tiedeman et al., 1994) They are based on the calibration of high frequency sedimentation cycles, or related cyclic variations, to computed time series of the quasi periodic variations of the Earth's orbit. The early tuning attempts for the late Pleitocene were performed by Cesare Emiliani who recently died (July 20, 1995). The astronomical time scale deviates from earlier time scales based on both magnetostratigraphic interpolation and K/Ar dating; it has been confirmed by Ar/Ar single crystal laser dating (Renne et al., 1994). It has been successfully applied also in palaeoclimatic studies (Lourens et al., 1992). The first attempts at extending the astronomical time scale back in time into the Miocene have been made by Shackleton et al. (1994) with the astronomical tuning of GRAPE records of ODP Leg 138 between 6 and 10 Ma, and by Krijgsman et al. (1994) calculating a duration of the late Miocene cyclic sequence of Crete as controlled by the precession period.

A direct calibration to astronomical target curves of the litho-cycles correlated from Crete to Gadvos and Sicily is proposed by Hilgen et al. (1995). The resulting time scale (see enclosed figs. 1-2) is also compared with 1) the most recent G(eomagnetic) P(olarity) T(ime) S(cale) of Cande & Kent (1995) and of Shackleton et al.(1995); 2) accurate Ar/Ar datings as those by Vai et al.(1993) and Laurenzi et al.(1995), and 3) the number of litho-cycles in the younger (hyper- and hypohaline) part of the peri-Adriatic and peri-Ionian Messinian (Vai, 1995) (see enclosed figs. 3-4).

Key references (including the remaining quotations)

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Table 1. Chronometric age calibration of the Tortonian/Messinian boundary in the last decades.

Author	Ma	Calibration tool
Evernden et al., 1961	>~12	radiometric
Kulp, 1961	>~13	"
Eberhardt & Ferrara, 1962	>~7	"
PTS (Harland et al.) 1964	>~7	"
Charlot et al., 1968; Choubert et al., 1968	6.5 to 8.0	"
Ryan et al., 1974 (*conomiozea* FAD)	6.2	magnetostratigraphic
" (T/M boundary)	6.6	"
Harland et al., 1982	6.2	"
Langereis et al., 1984	5.6	"
Berggren et al., 1985	6.5	"
Hsü, 1986	6.2 ±0.1	"
IUGS 1989	6.2	"
Harland et al., 1990	6.7	"
Odin, 1990	6.5	radiometric
Vai et al., 1992	<7.37±0.13	radiometric (K/Ar)
Cande & Kent, 1992	6.90 to 6.95	magnetostratigraphic
Vai et al., 1993	7.26±0.1	radiometric (K/Ar + Ar/Ar)
Baksi, 1993	7.03	magnetostratigraphic
Krijgsman et al., 1994	7.24	astrochronometric
Odin, 1994	7.1±0.3	radiometric
Cande & Kent, 1995	7.09 to 7.13	magnetostratigraphic
Laurenzi et al., 1995	7.15±0.04	radiometric (Ar/Ar)
Laurenzi & Montanari	7.17±0.06	"

Caption to figures in next pages

Fig. 1. Integrated magnetostratigraphic, biostratigraphic and cyclostratigraphic framework in the Mediterranean (after Hilgen et al., 1995 in press).

Fig. 2 Third-order correlations of individual sedimentation cycles to precession minima and of alternatingly thick/thin sapropel-cycles to interference patterns of precession and obliquity (after Hilgen et al., 1955 in press).

Fig. 3. Chronostratigraphic, magnetostratigraphic, cyclostratigraphic and radiometric framework of the Messinian formations and depositional sequences in the Northern Apennines (after Vai, 1995 in press).

Fig. 4. Preliminary cyclostratigraphic characterization of the late Tortonian-early Messinian euxinic shale formation, Romagna Apennine (after Vai, 1995 in press).

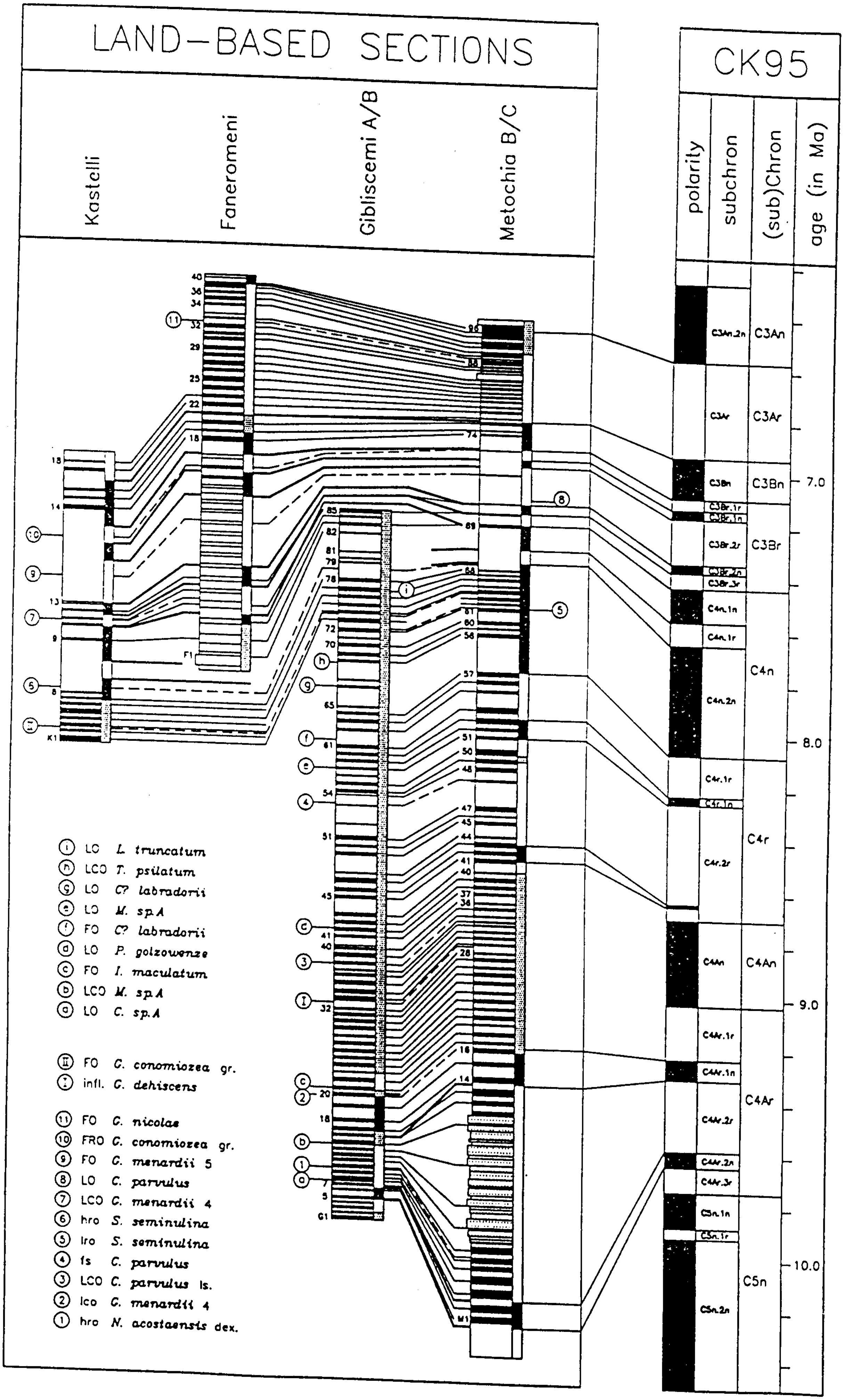
LAND-BASED SECTIONS
Kastelli
Faneromeni
Gibliscemi A/B
Metochia B/C
CK95
polarity
subchron
(sub)Chron
age (in Ma)
C3An.2n
C3An
C3Ar
C3Ar
C3Bn
C3Bn
C3Br.1r
C3Br.1n
C3Br.2r
C3Br
C3Br.2n
C3Br.3r
C4n.1n
C4n.1r
C4n
C4n.2n
C4r.1r
C4r.1n
C4r
C4r.2r
C4An
C4An
C4Ar.1r
C4Ar.1n
C4Ar
C4Ar.2r
C4Ar.2n
C4Ar.3r
C5n.1n
C5n.1r
C5n
C5n.2n
7.0
8.0
9.0
10.0
(i) LO L. truncatum
(h) LCO T. psilatum
(g) LO C? labradorii
(e) LO M. sp.A
(f) FO C? labradorii
(d) LO P. golzowense
(c) FO I. maculatum
(b) LCO M. sp.A
(a) LO C. sp.A
(II) FO G. conomiozea gr.
(I) infl. G. dehiscens
(11) FO G. nicolae
(10) FRO G. conomiozea gr.
(9) FO G. menardii 5
(8) LO C. parvulus
(7) LCO G. menardii 4
(6) hro S. seminulina
(5) lro S. seminulina
(4) fs C. parvulus
(3) LCO C. parvulus ls.
(2) lco G. menardii 4
(1) hro N. acostaensis dex.

Fig. 1

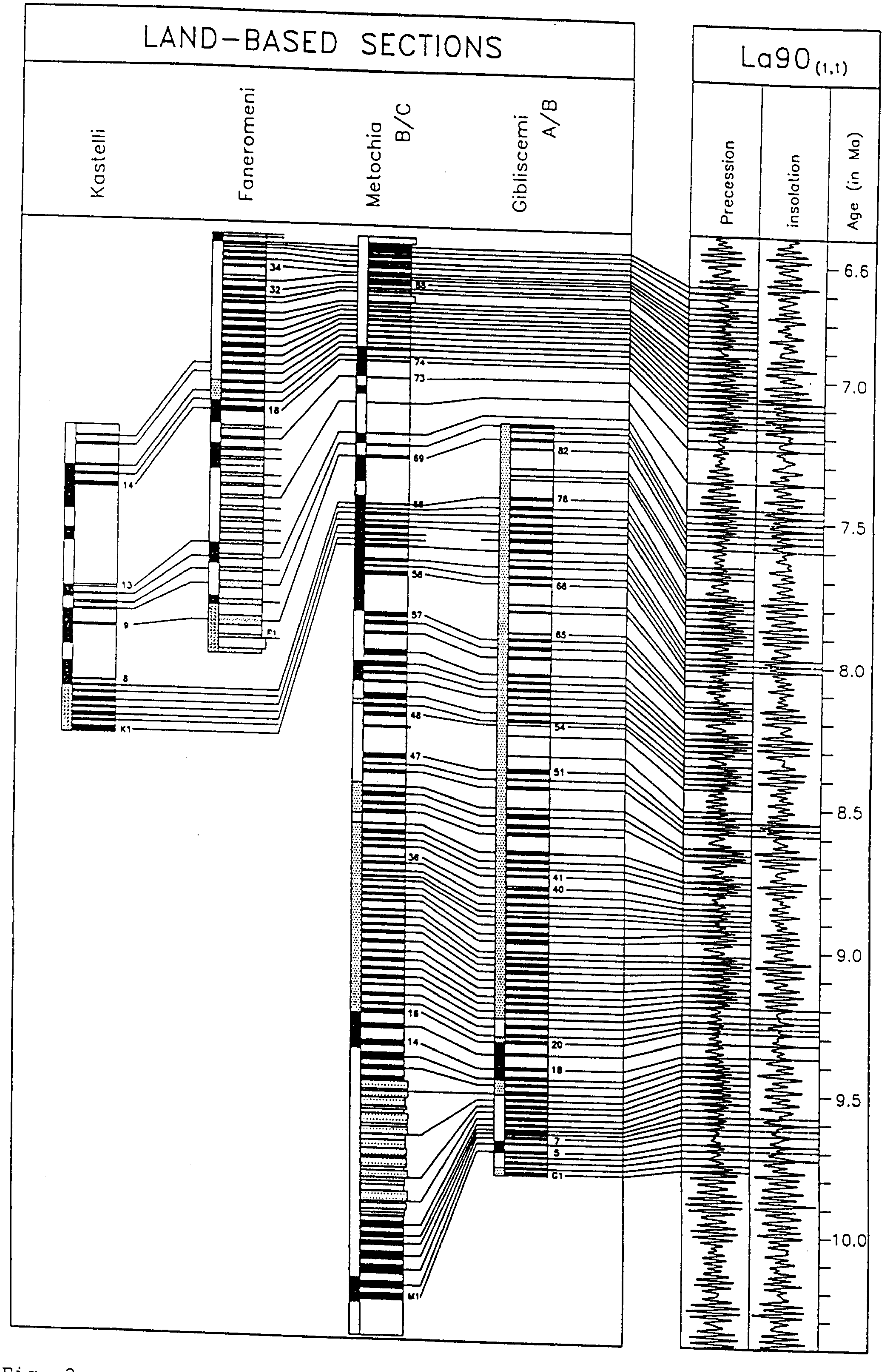
LAND-BASED SECTIONS
Kastelli
Faneromeni
Metochia B/C
Gibliscemi A/B
La90(1,1)
Precession
insolation
Age (in Ma)
6.6
7.0
7.5
8.0
8.5
9.0
9.5
10.0

Fig. 2

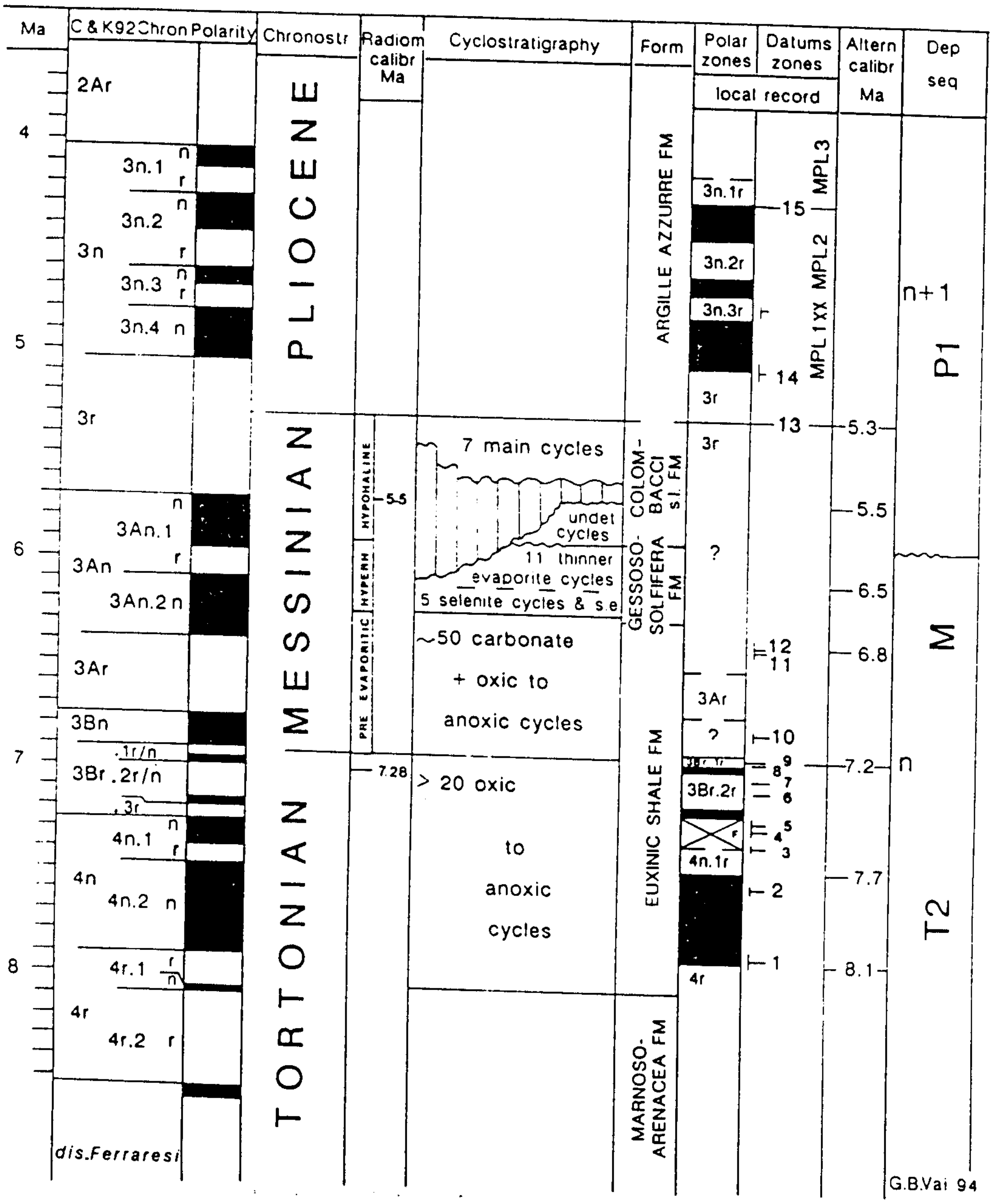
Ma
C & K92 Chron Polarity
Chronostr
Radiom calibr Ma
Cyclostratigraphy
Form
Polar zones
Datums zones
local record
Altern calibr Ma
Dep seq
2Ar
3n.1
3n.2
3n
3n.3
3n.4
3r
3An.1
3An
3An.2
3Ar
3Bn
3Br
4n.1
4n
4n.2
4r.1
4r
4r.2
dis.Ferraresi
PLIOCENE
MESSINIAN
TORTONIAN
HYPOHALINE
HYPERH
PRE EVAPORITIC
5.5
7.28
7 main cycles
undet cycles
11 thinner evaporite cycles
5 selenite cycles & s.e
~50 carbonate + oxic to anoxic cycles
> 20 oxic to anoxic cycles
ARGILLE AZZURRE FM
COLOMBACCI s.l. FM
GESSOSO-SOLFIFERA FM
EUXINIC SHALE FM
MARNOSO-ARENACEA FM
3n.1r
3n.2r
3n.3r
3Ar
3Br.2r
4n.1r
MPL3
MPL2
MPL1XX
-5.3-
-5.5
-6.5
-6.8
-7.2-
-7.7
-8.1-
n+1
P1
M
n
T2
G.B.Vai 94

Fig. 3

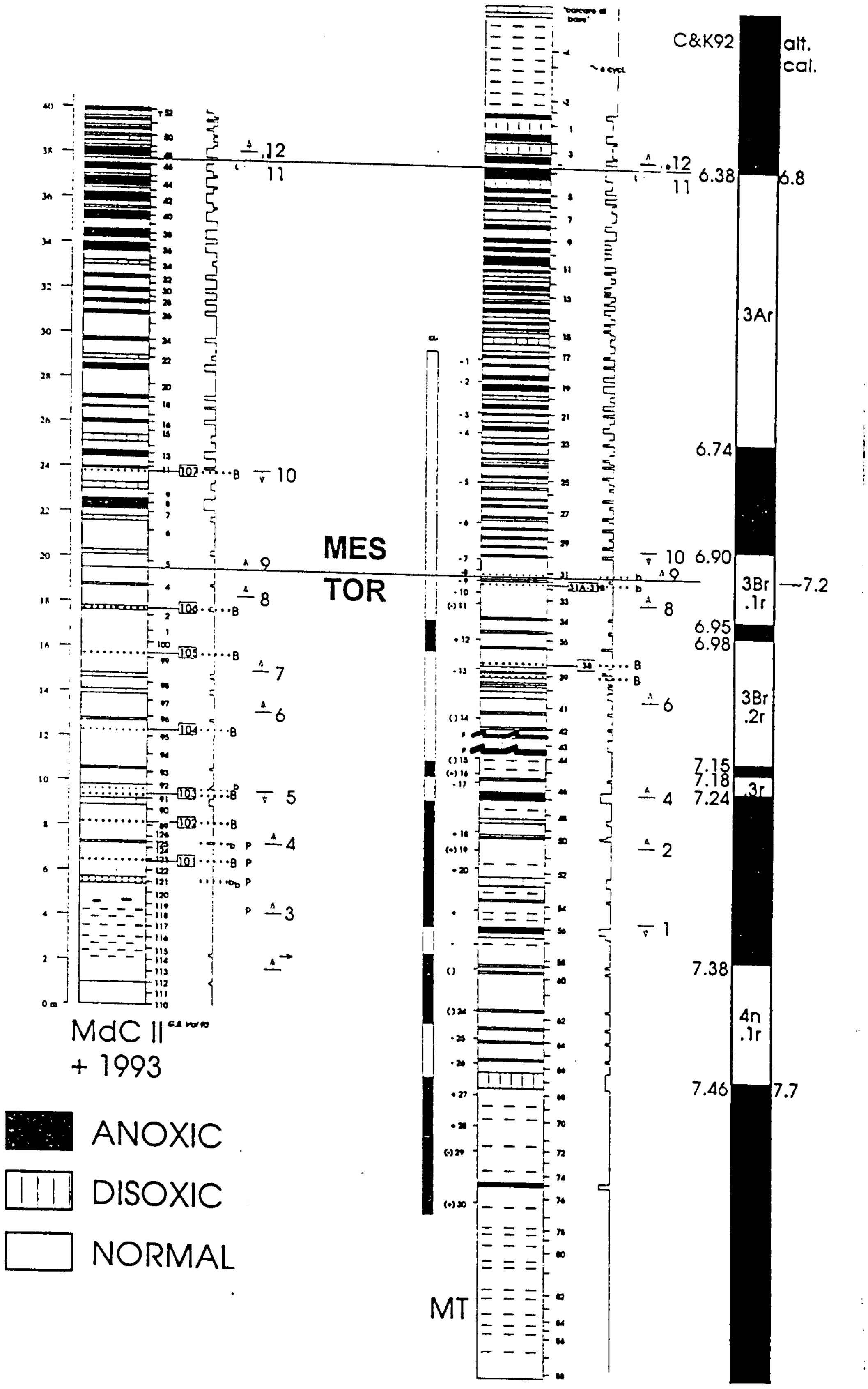
C&K92
alt. cal.
6.38
6.8
3Ar
6.74
6.90
3Br .1r
7.2
6.95
6.98
3Br .2r
7.15
7.18
3r
7.24
7.38
4n .1r
7.46
7.7
MES
TOR
MdC II
+ 1993
MT
ANOXIC
DISOXIC
NORMAL

Fig. 4