TECTONICS, MAGMATISM AND GEODYNAMICS OF ITALY. WHAT WE KNOW AND WHAT WE IMAGINE.

THE MOVIE

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CAVEATS AND UNCERTAINTIES

Although a full and detailed description of the evolution of the entire western and central Mediterranean region is beyond the scope of the paper attached to this movie, the movie includes also features external to the Italian area (e.g., Pyrenees, Dinarides, Betics, Rif, Maghrebides, Carpathians, Pannonian Basin). This was done in order to place the geodynamic evolution of the Italian region in a more regional context. For more details on the evolution of the Mediterranean region and for alternative views, the reader is referred to previous reviews of the geology and geodynamics of the central and western Mediterranean area (e.g., Faccenna et al., 1997. Carminati et al., 1998; Gueguen et al., 1998; Wortel and Spakman, 2000; Tari, 2002; Csontos and Voros, 2004; Carminati and Doglioni, 2005; Rosenbaum and Lister, 2004; Mauffret, 2007; Chalouan et al., 2008). The movie is intended to be as much rigorous as possible. However, the scale of the representation and the complexity of the evolution of the region are such that some features had to be represented in a schematic way. For example, the normal faults associated with the opening of the back-arc basins are not to be taken as representative of real faults but indicate the location where normal faulting occurred. Moreover, we admit the following uncertainties and under-constraints in the paleogeographic reconstructions. A general (and easily understandable) rule is that the uncertainties are larger for older time frames. In the 50-40 Ma frames of the movie, the geometry of the Liguro-Piedmont-Penninic Ocean is largely speculative. Another poorly constrained point is the contact between the Betics and Rif mountain belts. As concerns the age of the igneous activity, most of the geochronological data are incomplete and scattered (no systematic cover exists). Most of the isotopic ages are based on old (produced during '70s-'80s) K-Ar ages and only very few are based on detailed $^{40}Ar/^{39}Ar$ ages. Moreover, the ages should be considered only as the youngest limit, no one knowing exactly when igneous activity started in these igneous districts.

Central-Western Mediterranean Cenozoic igneous rocks

"Anorogenic" or "within-plate-like" igneous rocks

(mostly tholeiitic to sodic alkaline, with very rare potassic, ultrapotassic alkaline rocks and carbonatites).

RED = Active **PINK = Extinct**

"Orogenic" or "subduction-related" igneous rocks

(mostly calcalkaline to potassic and ultrapotassic alkaline rocks, with rare arc-tholeiites, lamproites, lamprophyres, kamafugites and carbonatites).

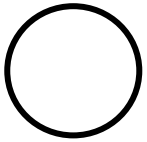
BLUE = Active **SKY BLUE = Extinct**

MORB-like *(either E- T- or N-type; Enriched, Transitional, Normal)*

BLACK = Active **GREY = Extinct**

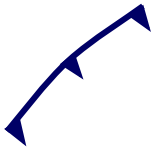
Volcanic and Pyroclastic

Volcaniclastic



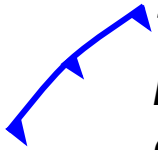
Plutonic

Dyke (hypoabyssal)



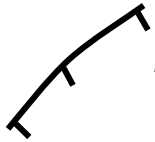
Thrust fronts associated with **east-***directed subduction* *and collision zones*

Thrust fronts associated with **west-***directed subduction* *and collision zones*



Thrust fronts associated with retrobelts in double-verging orogens

Active normal faults



Border of back-arc basins

Inactive normal faults

Inverted intracontinental basins

Backarc stretched continental lithosphere in the Alpine foreland

Alpine-Betic and Dinarides-Hellenides Belts

Backarc stretched areas previously belonging to Alpine-Betic and Dinarides Belts

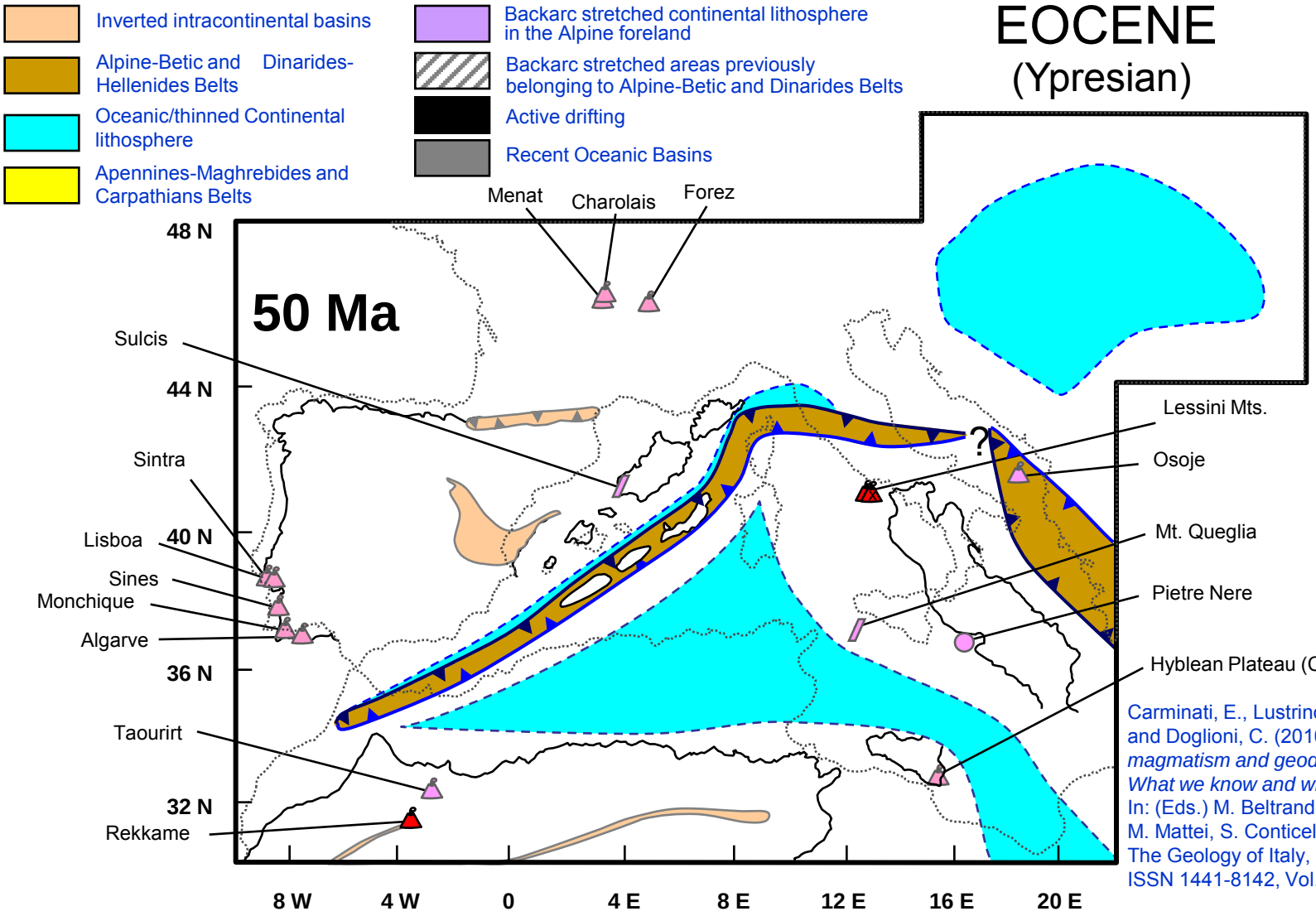
Oceanic/thinned Continental lithosphere

Active drifting

Apennines-Maghrebides and Carpathians Belts

Recent Oceanic Basins

EOCENE
(Ypresian)



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The consumption of the Alpine Tethys is already completed through SE-directed subduction associated with the Alpine orogen. No subduction-related igneous activity in the Alps. No clear lateral continuity between Alpine and Dinaride systems. Neo-Tethys (Ionian oceanic lithosphere) not subducted.

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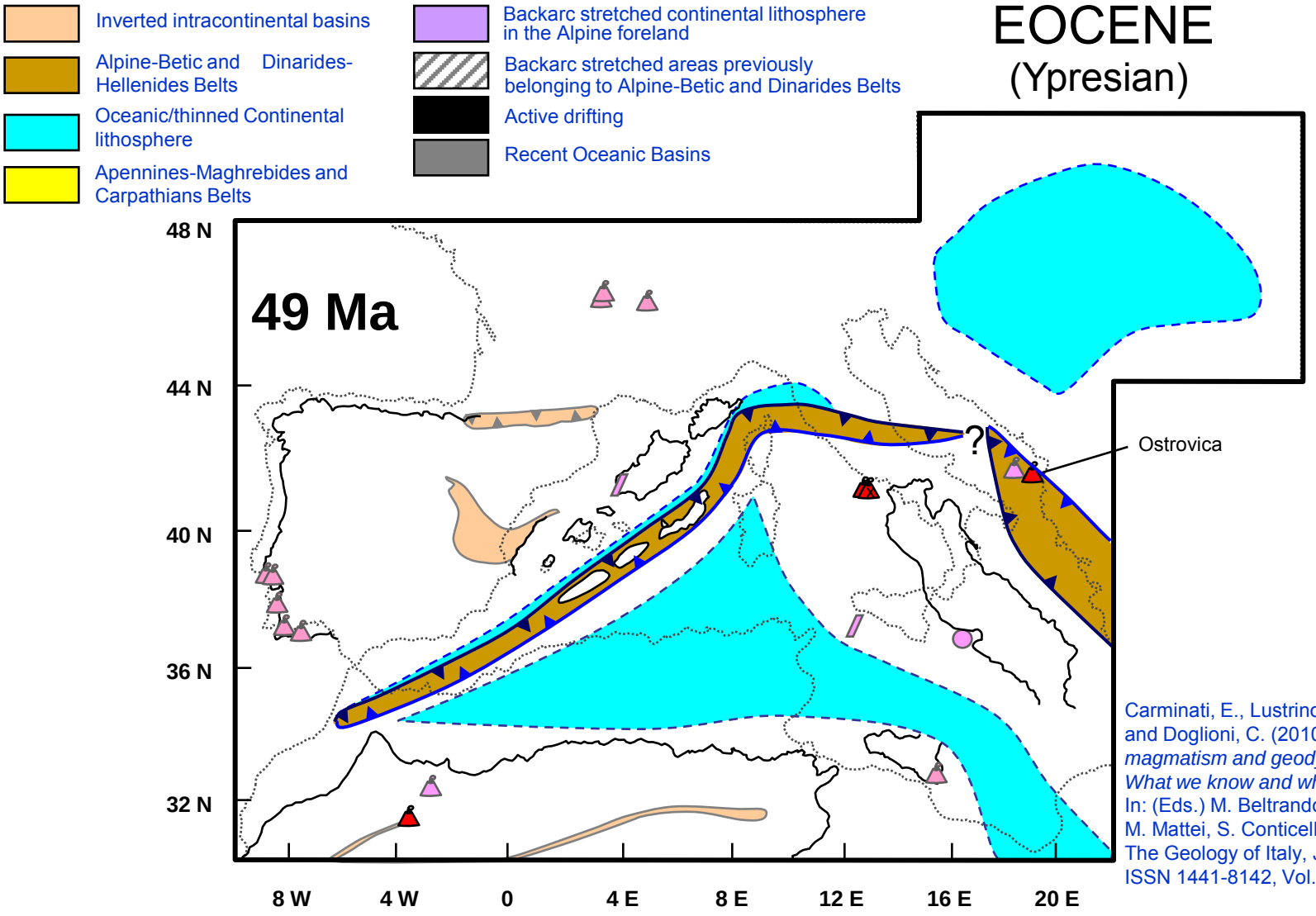
(Ypresian)



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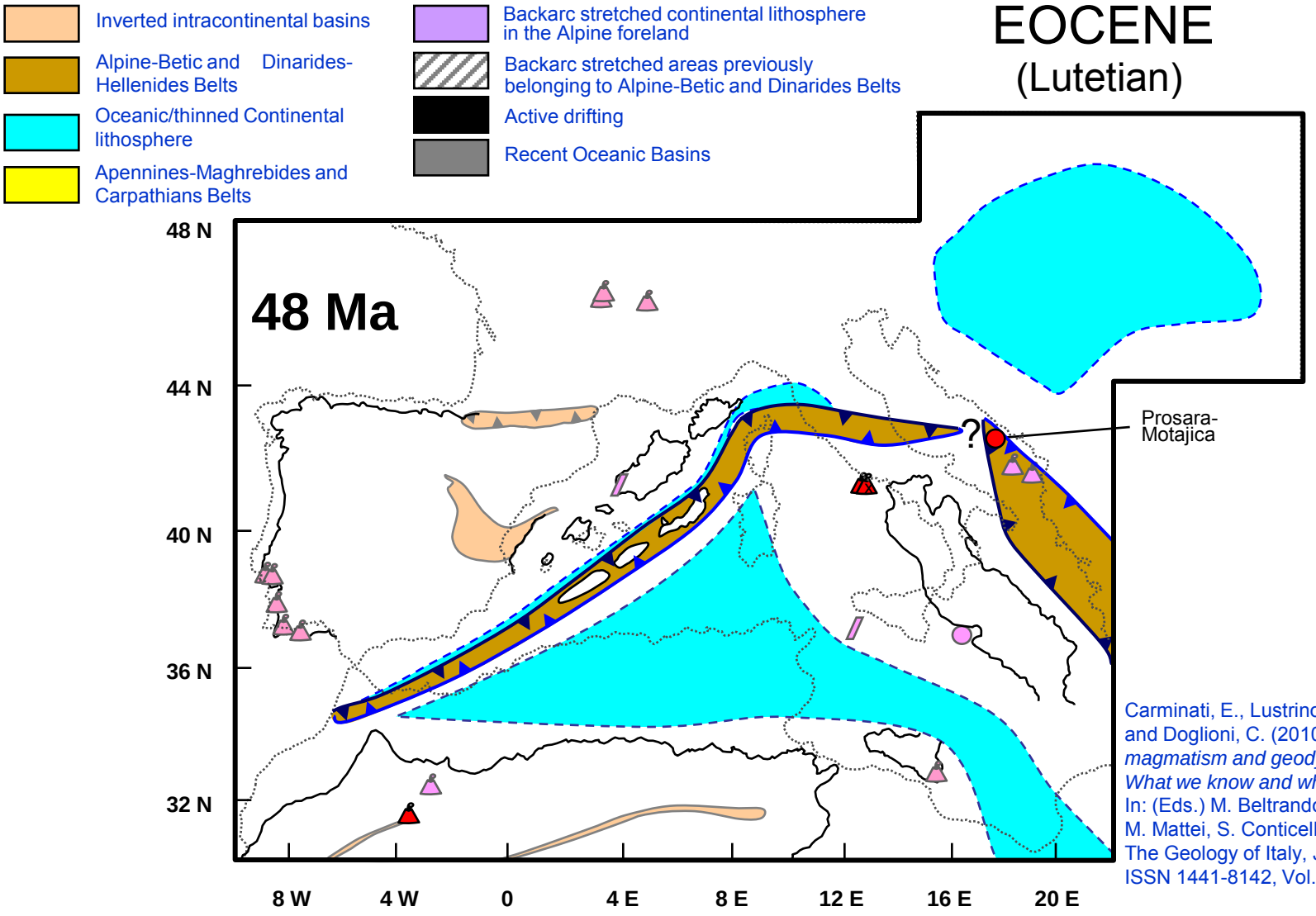
EOCENE
(Lutetian)



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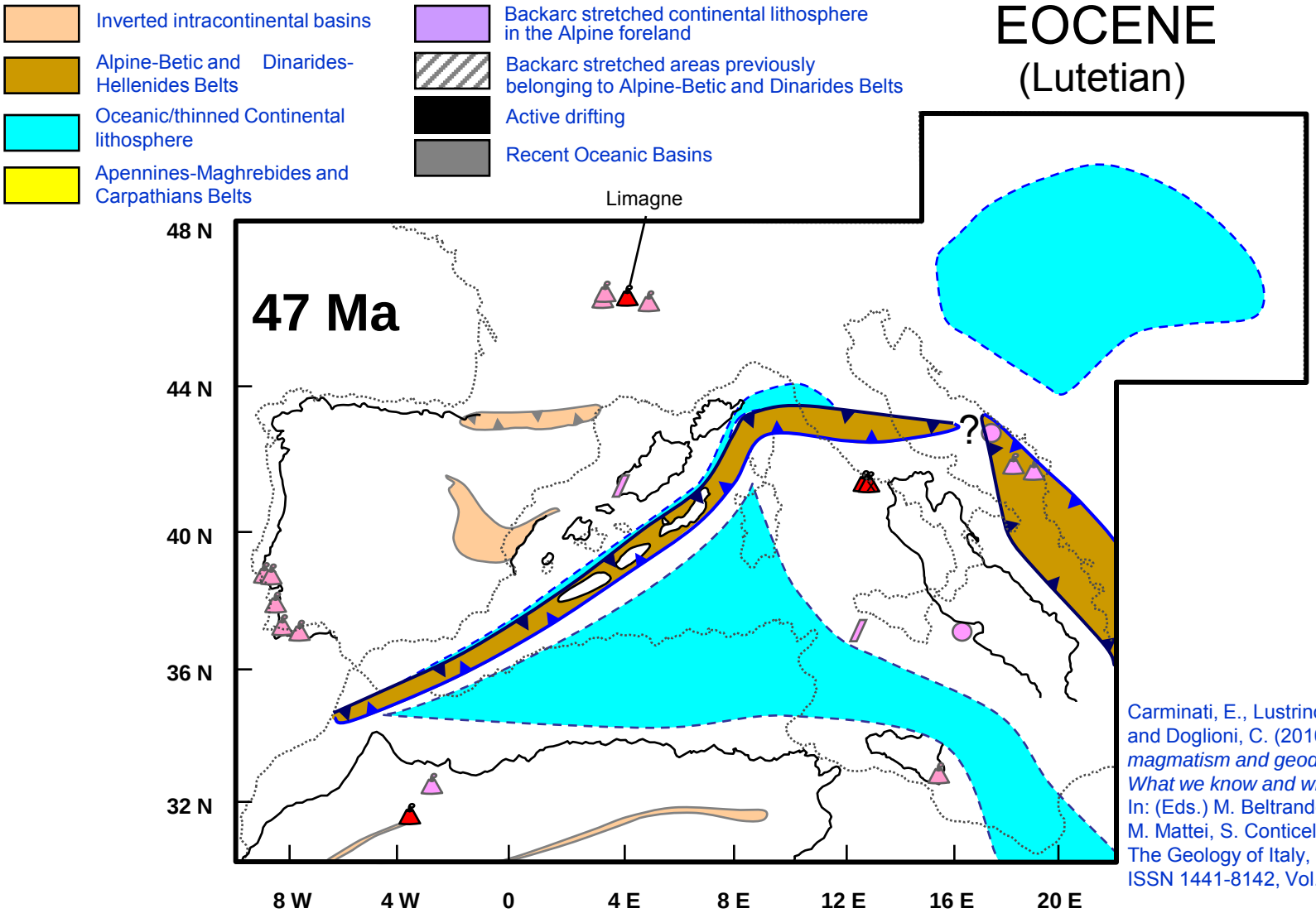

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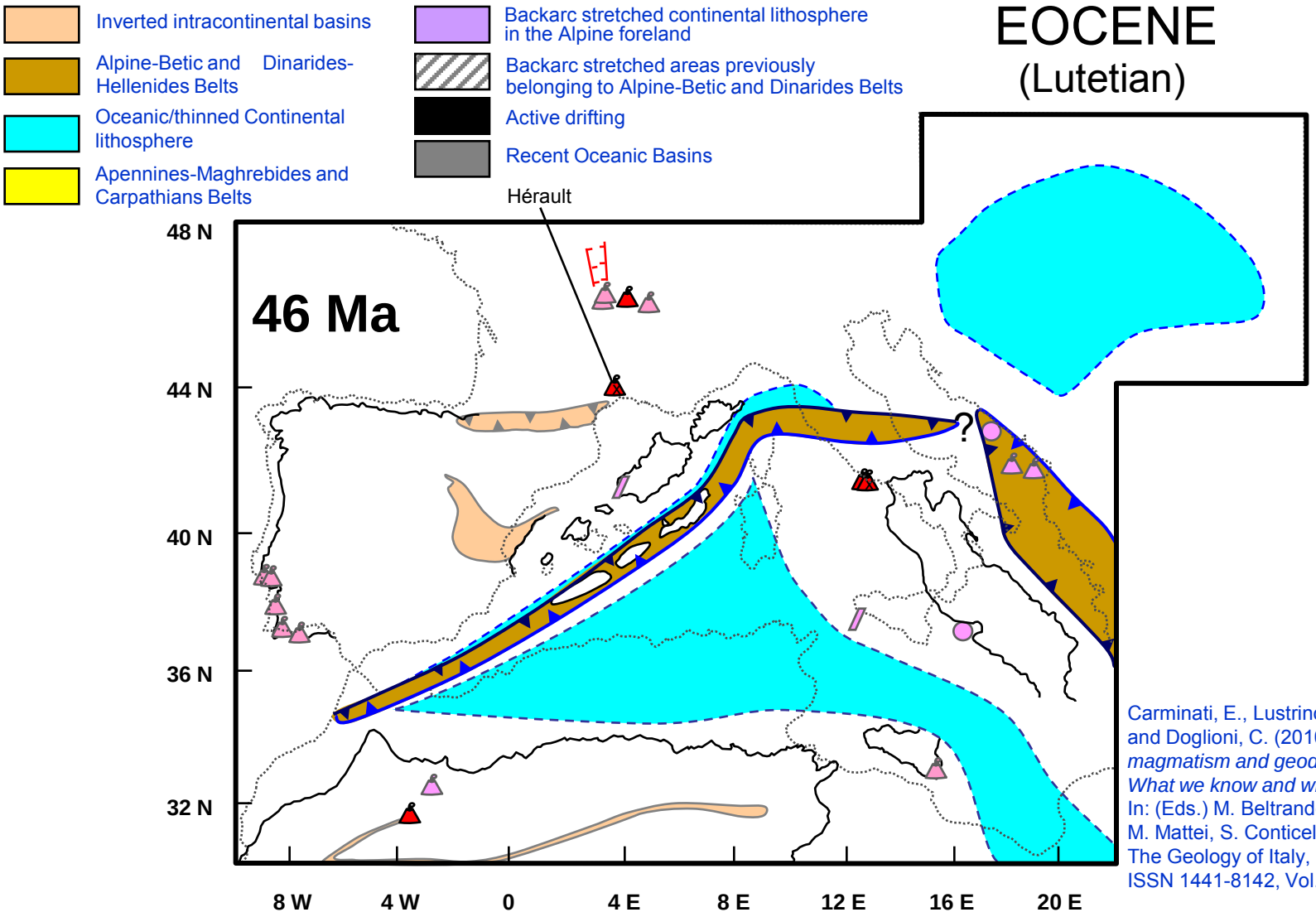

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Onset of the European Cenozoic RIft System (ECRIS).

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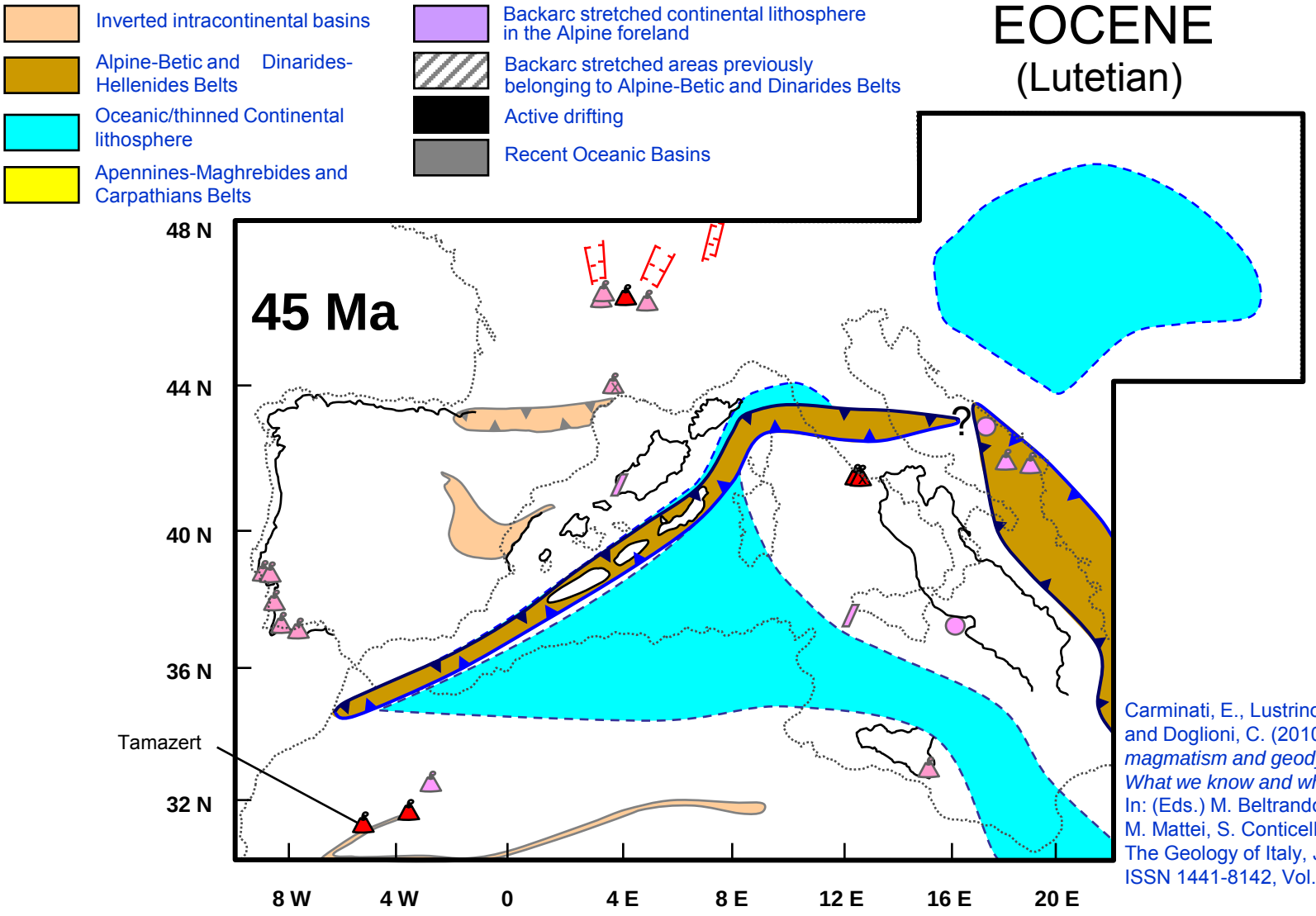
(Lutetian)



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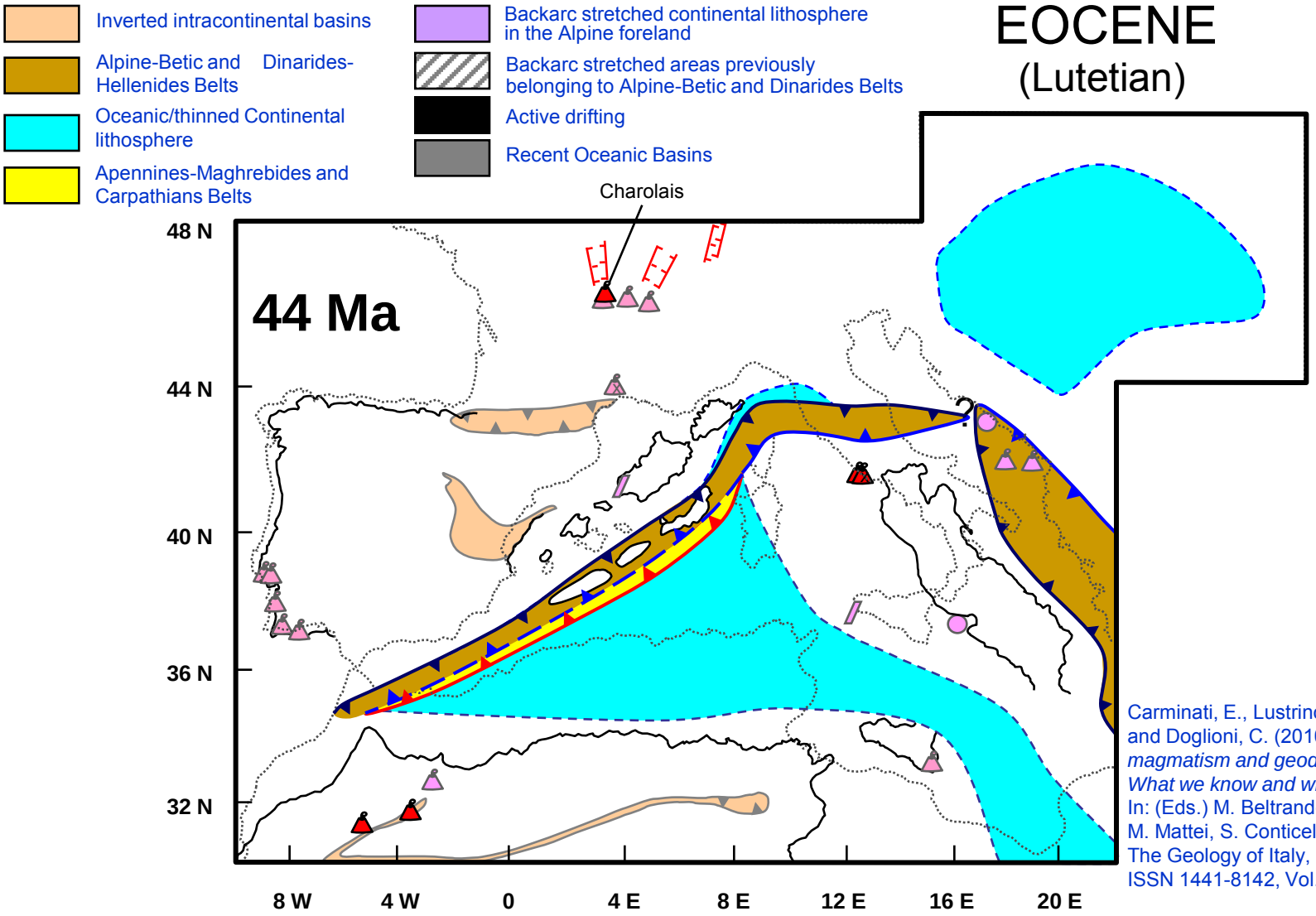
(Lutetian)



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Beginning of the NW-directed (and SE-radially retreating) Apennine-Maghrebide subduction, developed along the Alpine-Betic retrobelt.

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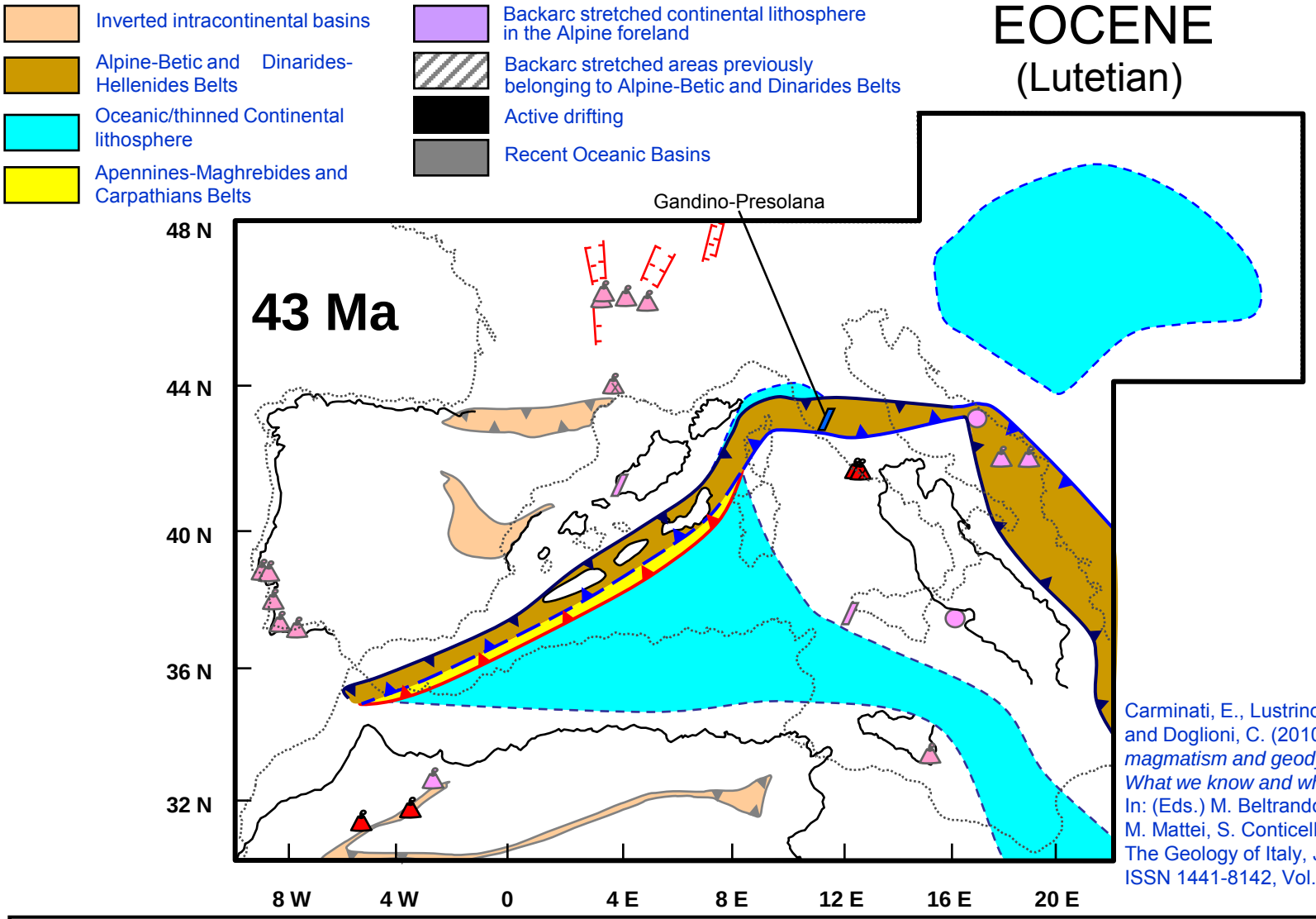
(Lutetian)



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First dated cases of “orogenic” volcanic activity in the Alps. Alpine-Dinaride orogens possibly merging.

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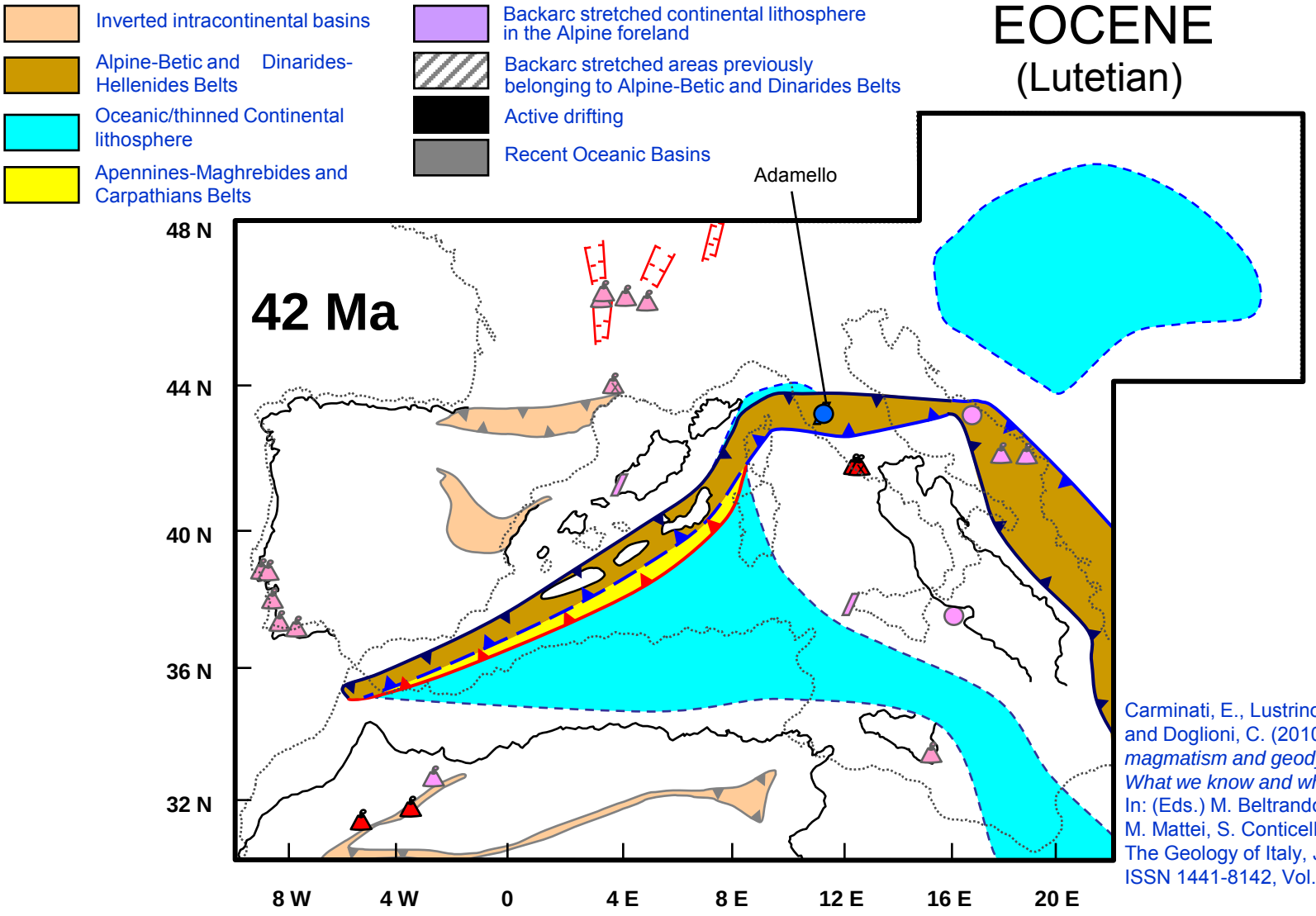
(Lutetian)



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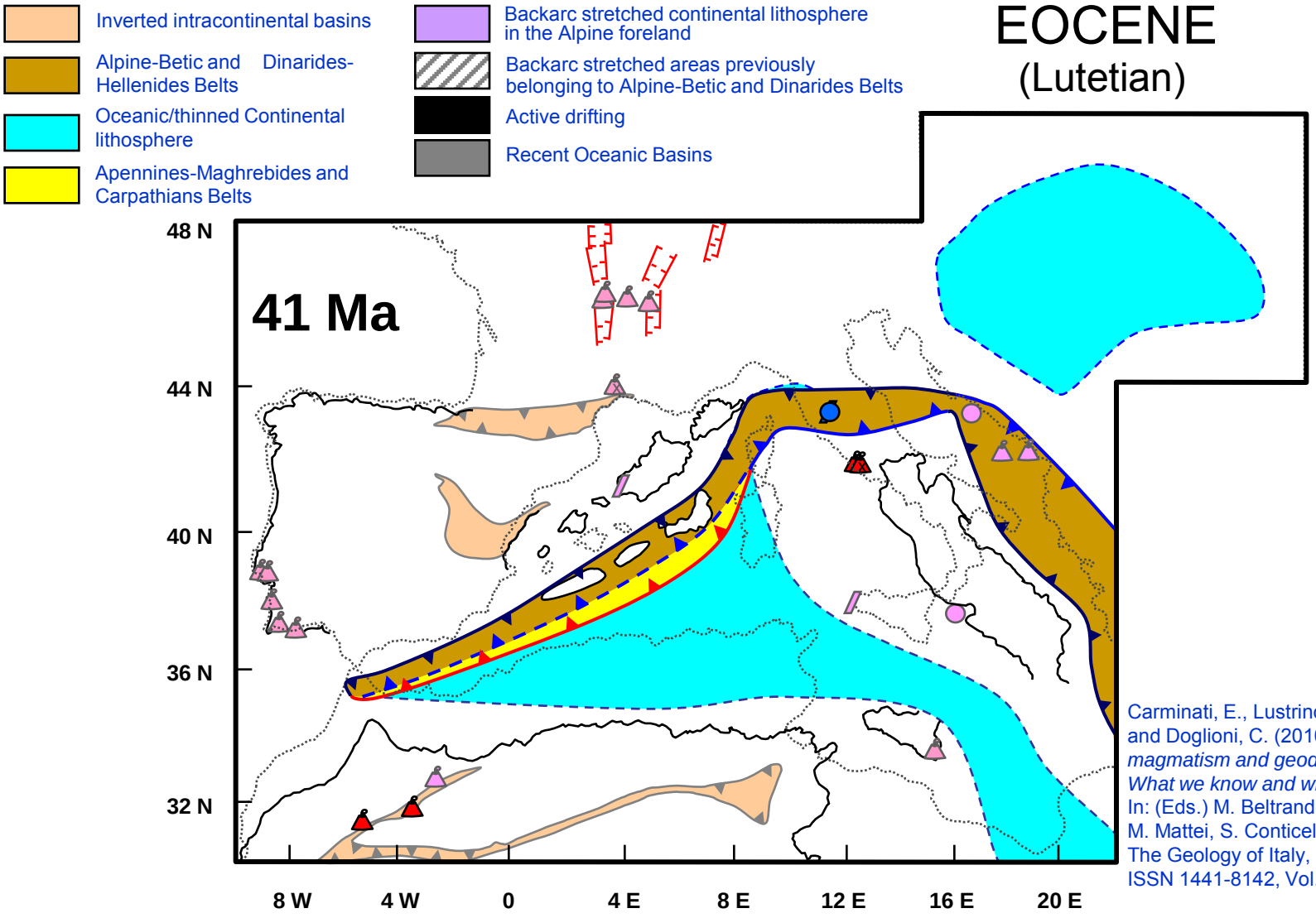

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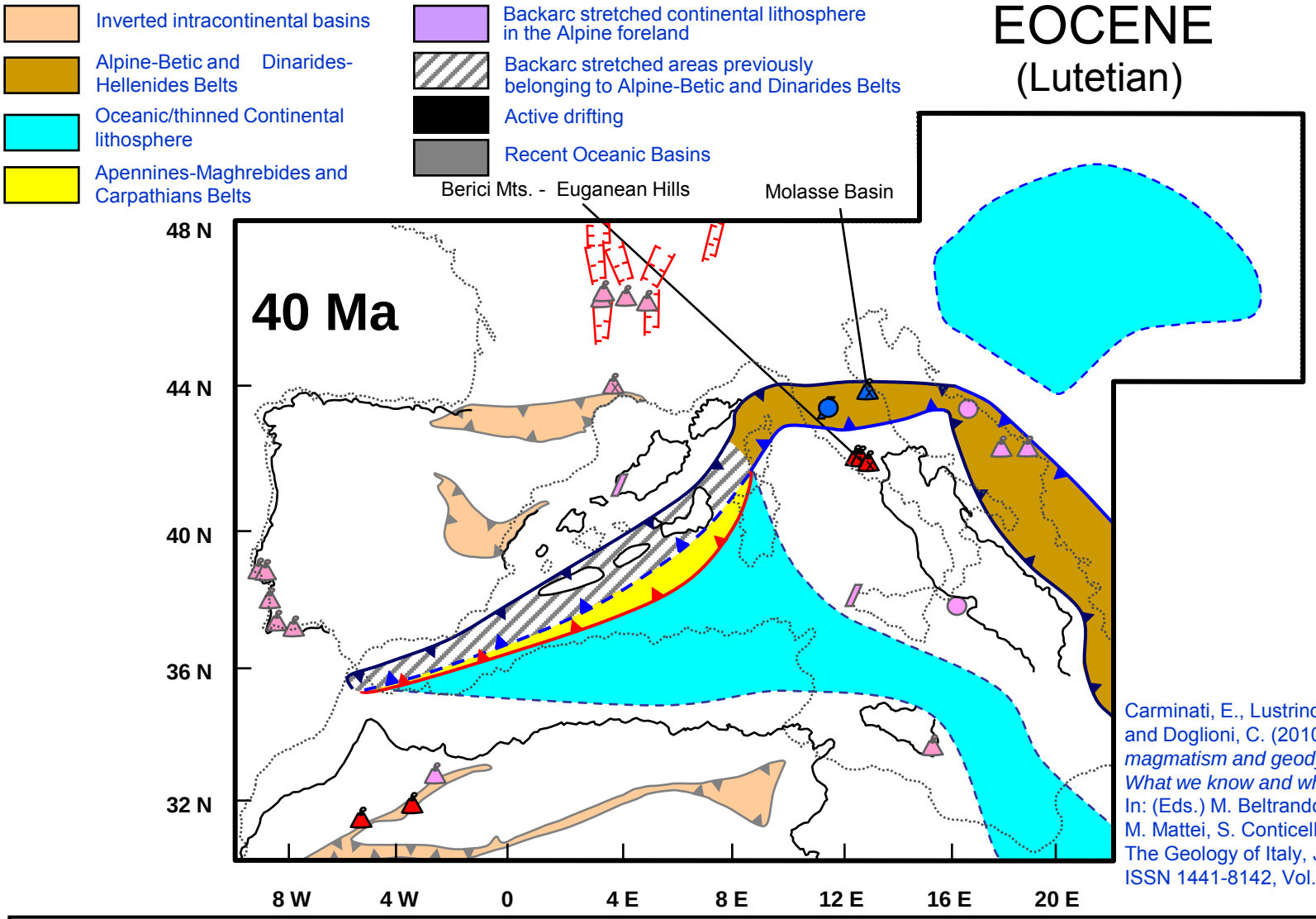

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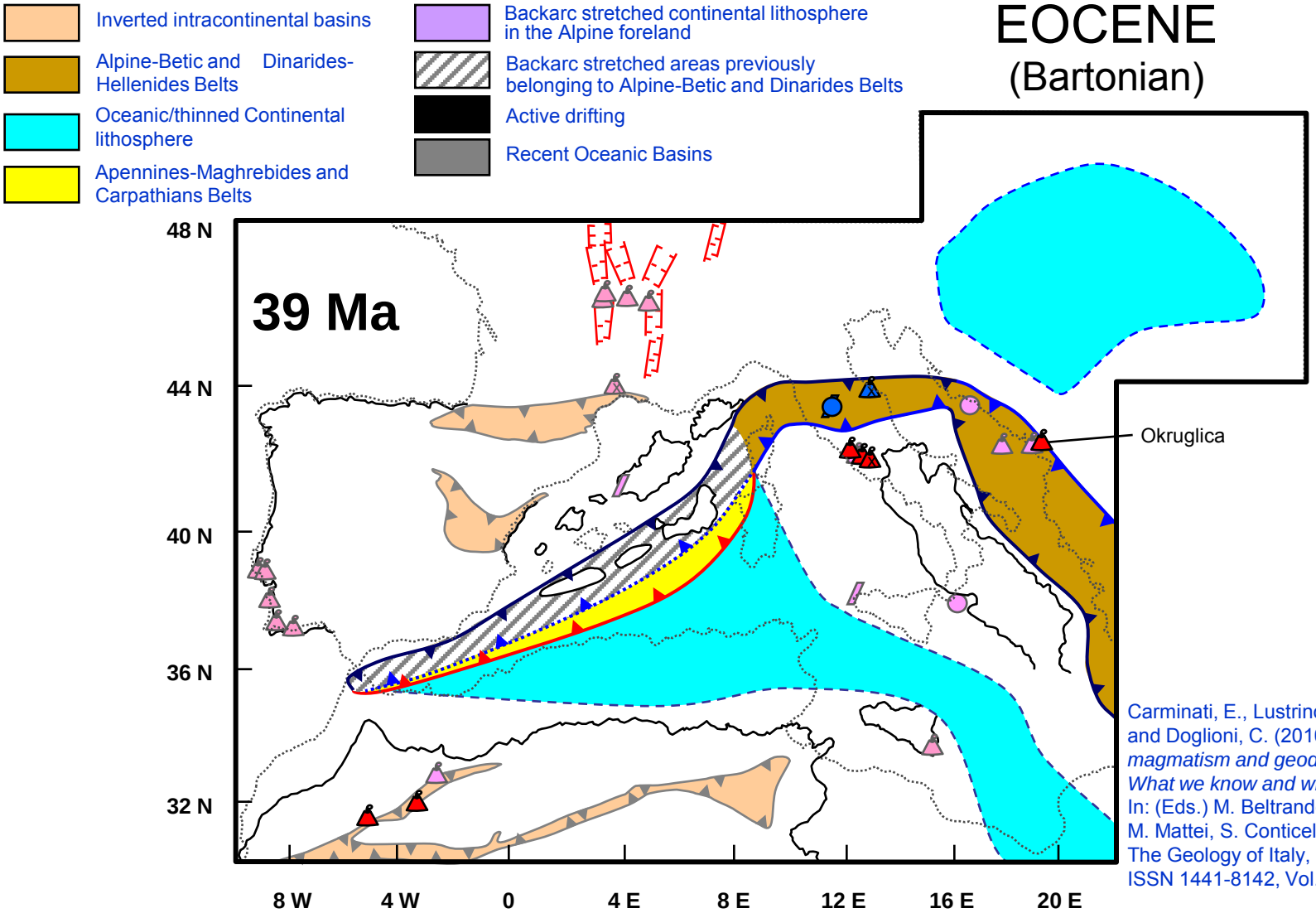
Last Alpine Tethys remnant disappears. Apennine-Maghrebide thrusts start developing. Development of wedge-top basins onto Apennines thrust units. Shortening recorded in Atlas, Iberian Chain, Pyrenees and Alps. Beginning of disruption of the Alpine belt by extensional tectonics in the embryonic back-arc of the Apennines subduction.

EOCENE
(Bartonian)



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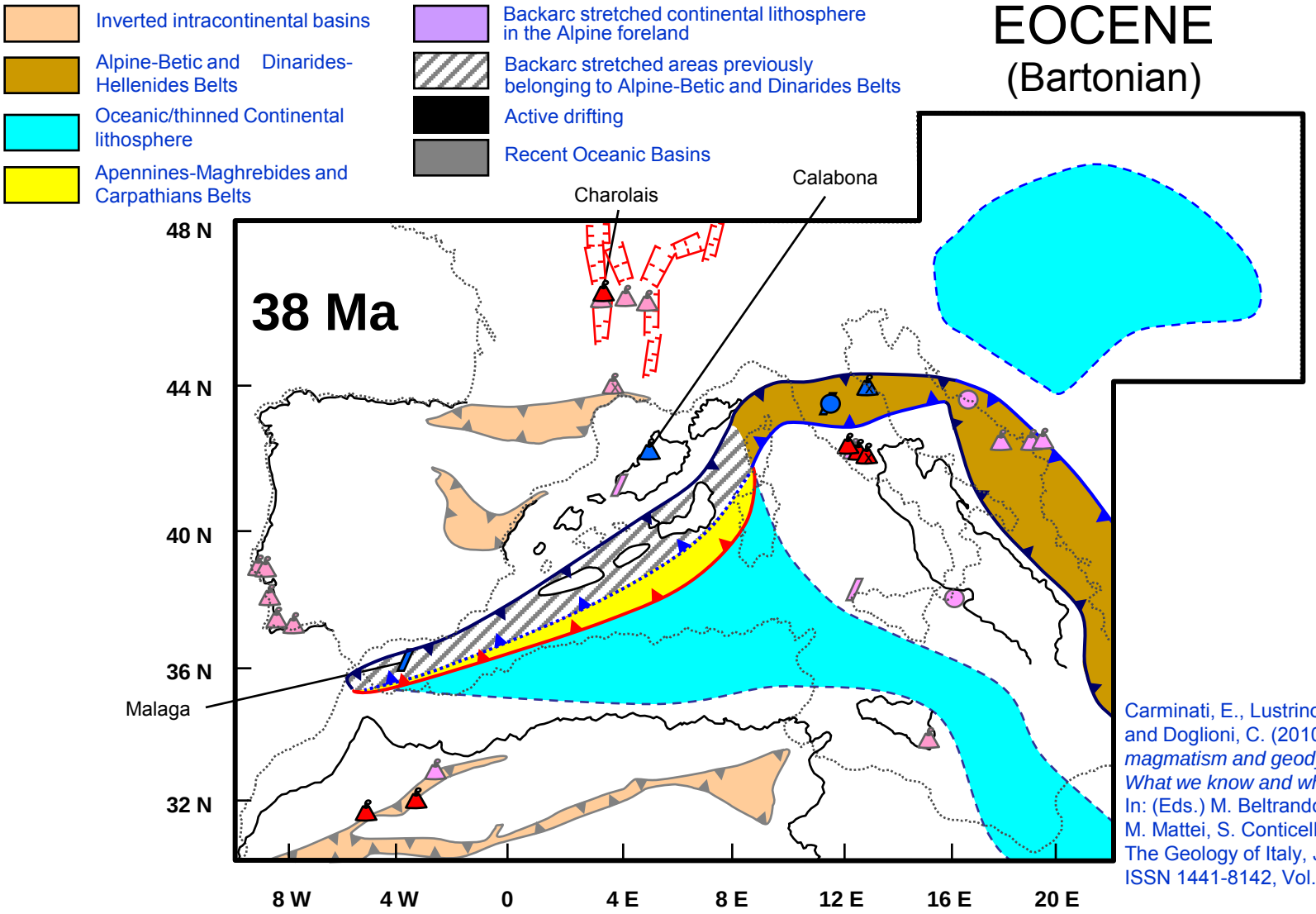
(Bartonian)



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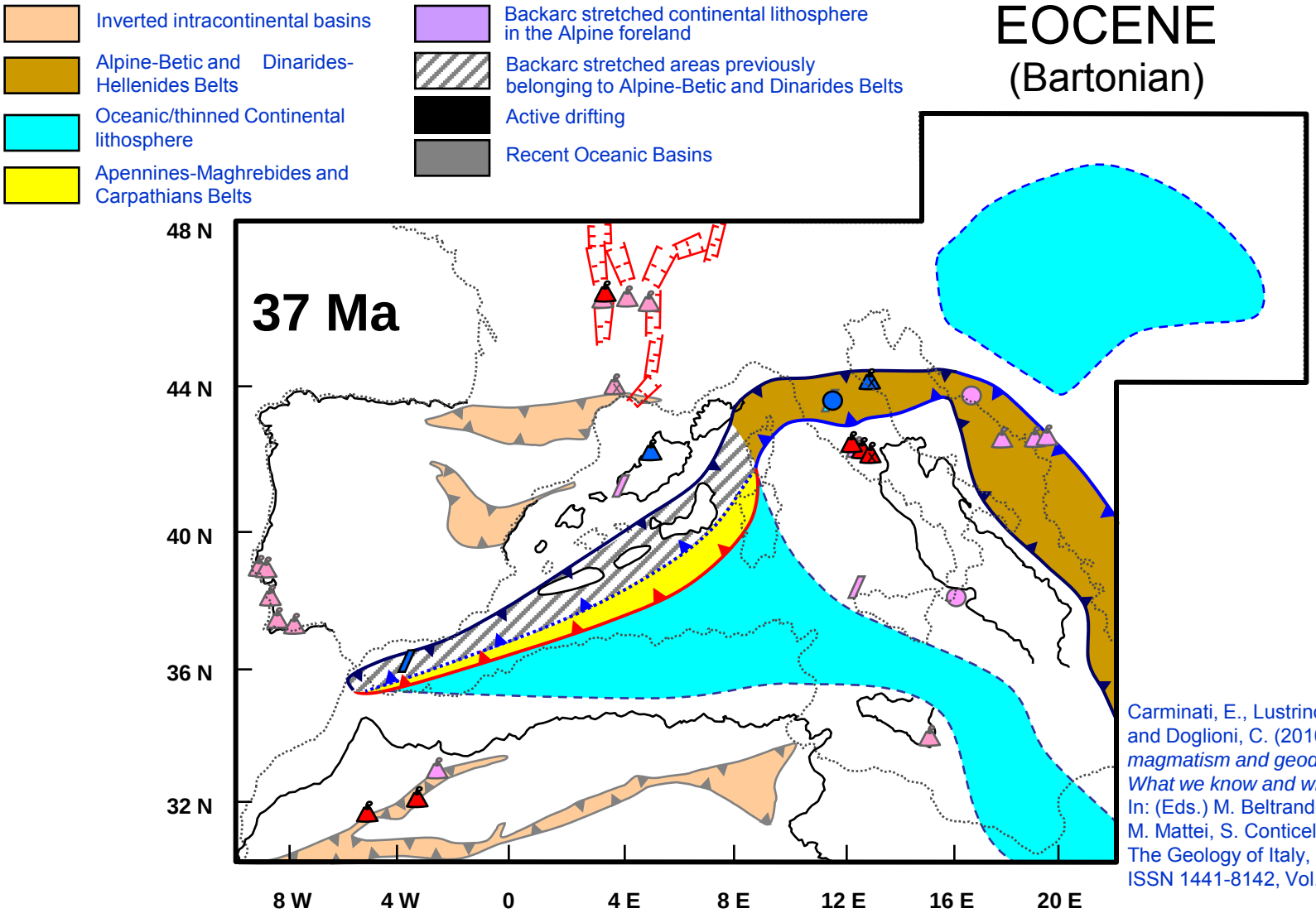
First Apennine subduction-related igneous activity in Sardinia and S Spain. Corsica experiences continental collision.

EOCENE
(Bartonian)



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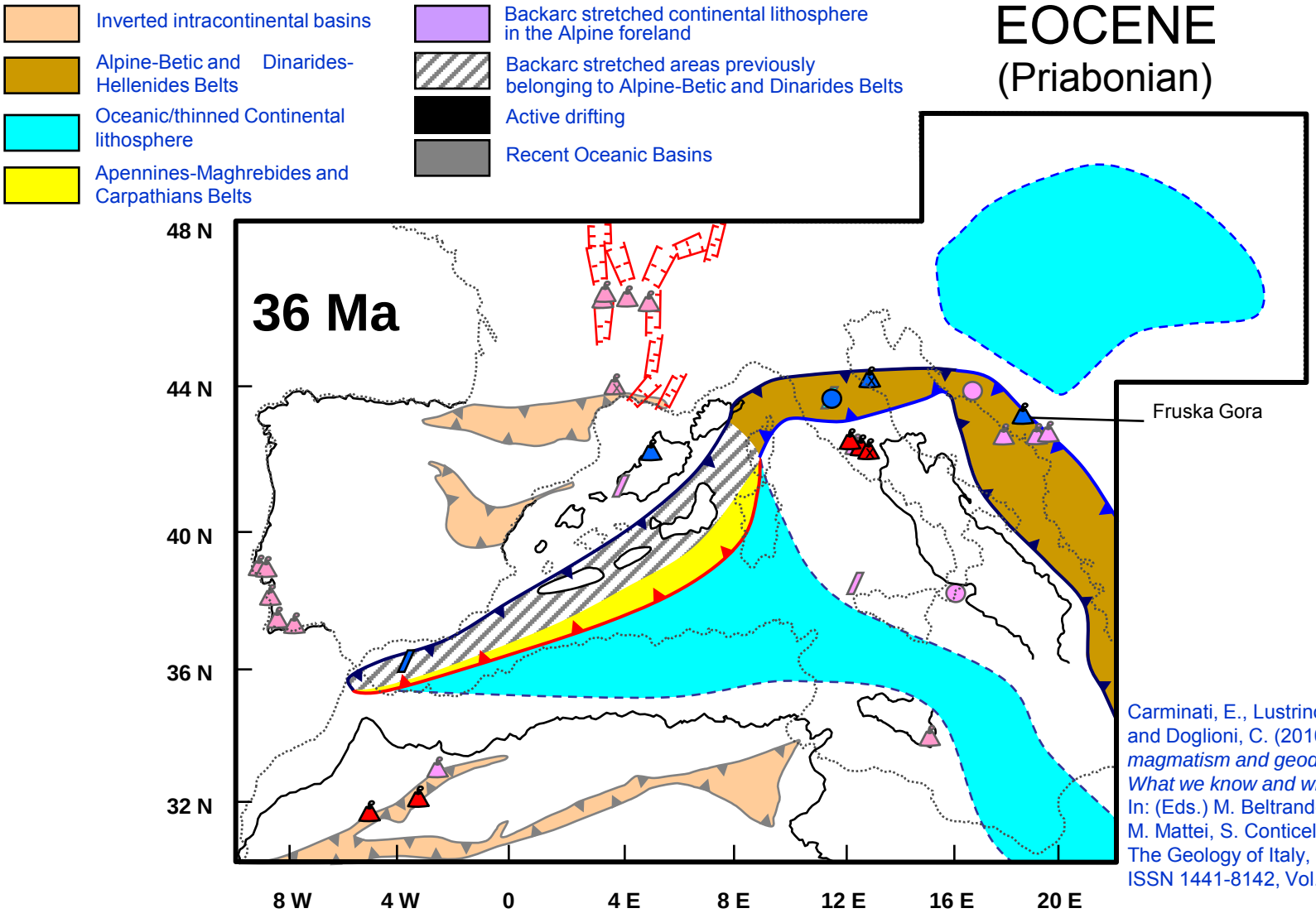
EOCENE
(Priabonian)



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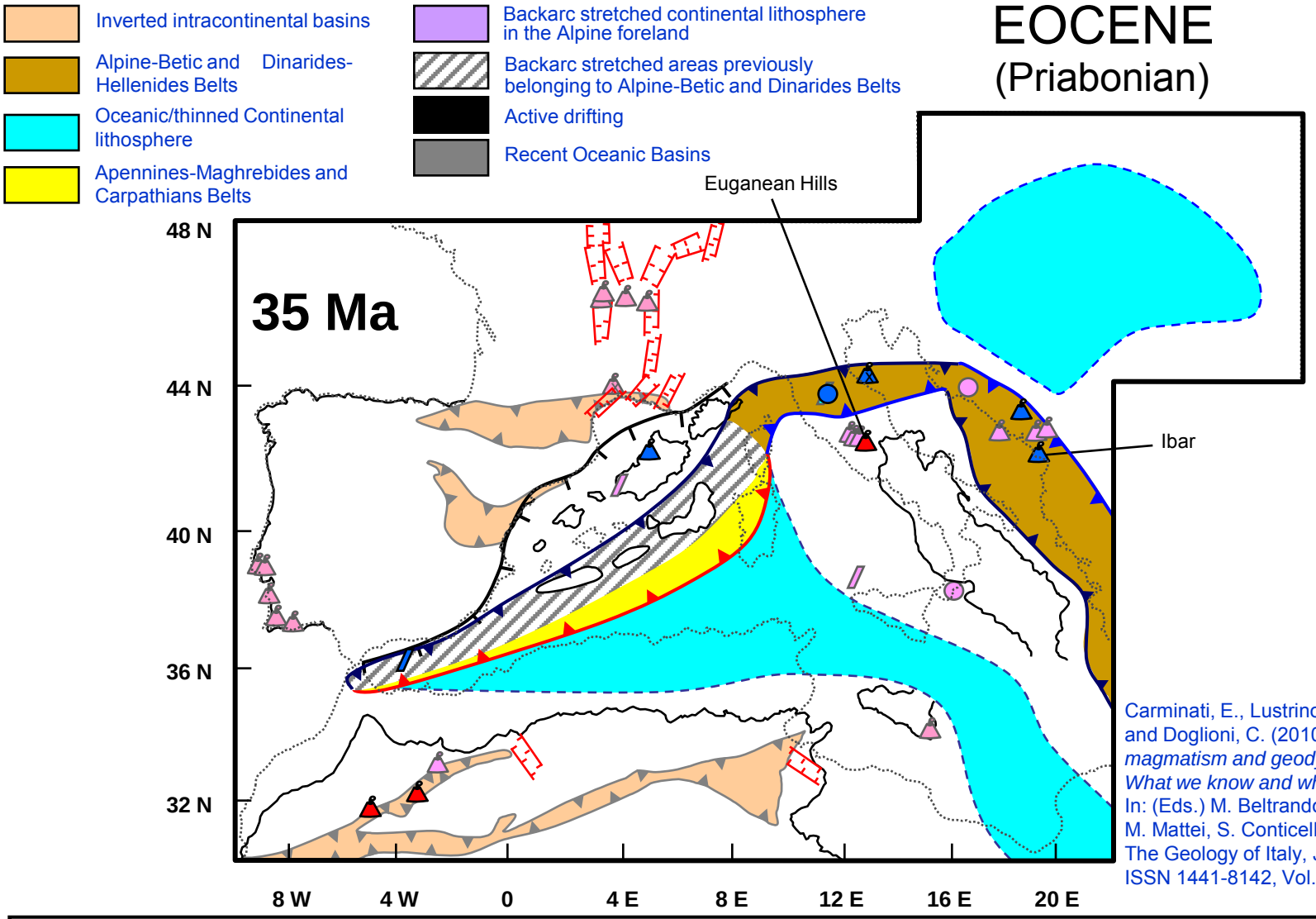
(Priabonian)



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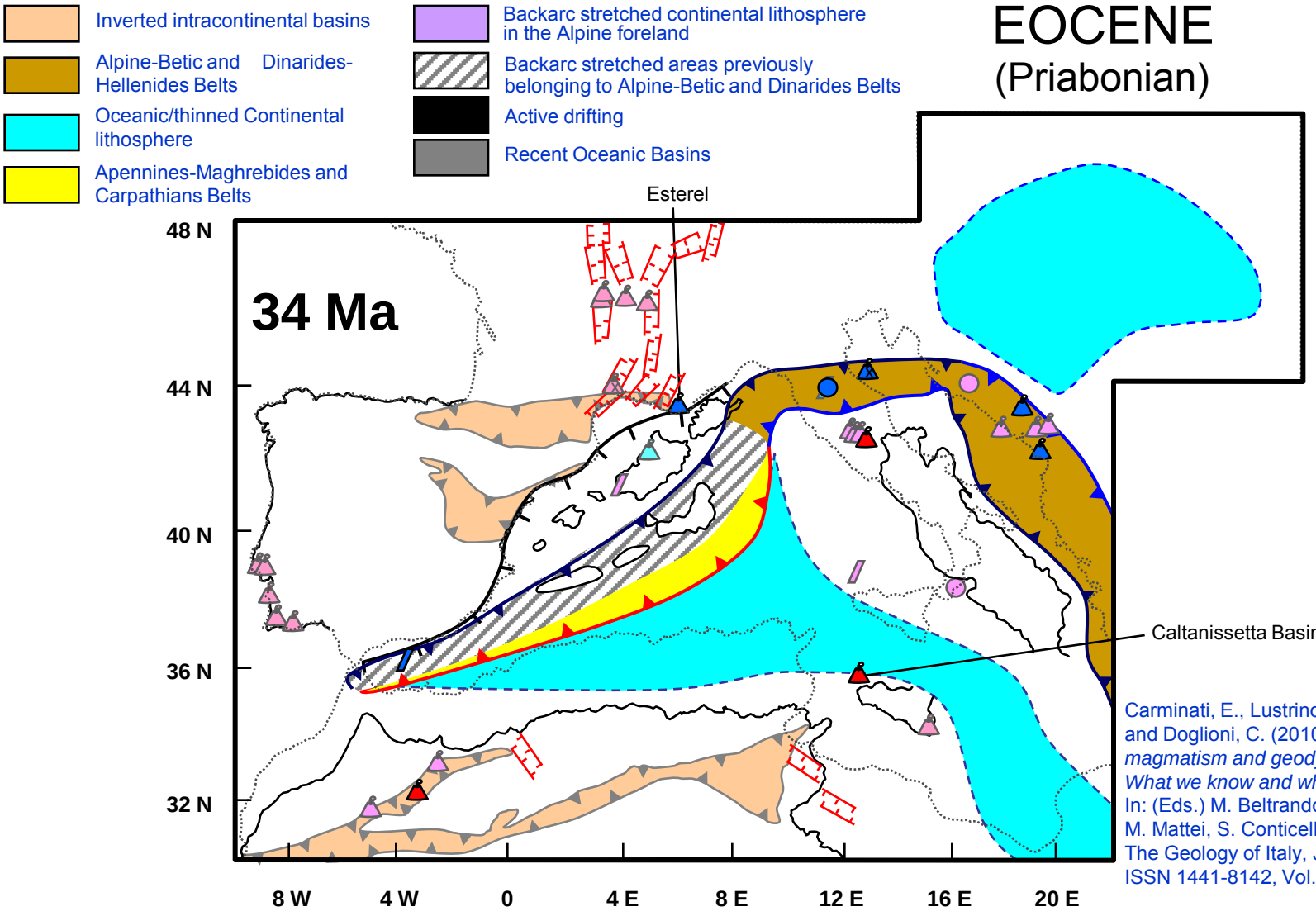
Significant stretching in the W Mediterranean back-arc basins. Stretching also in the Algerian and Tunisian Atlas.

EOCENE
(Priabonian)



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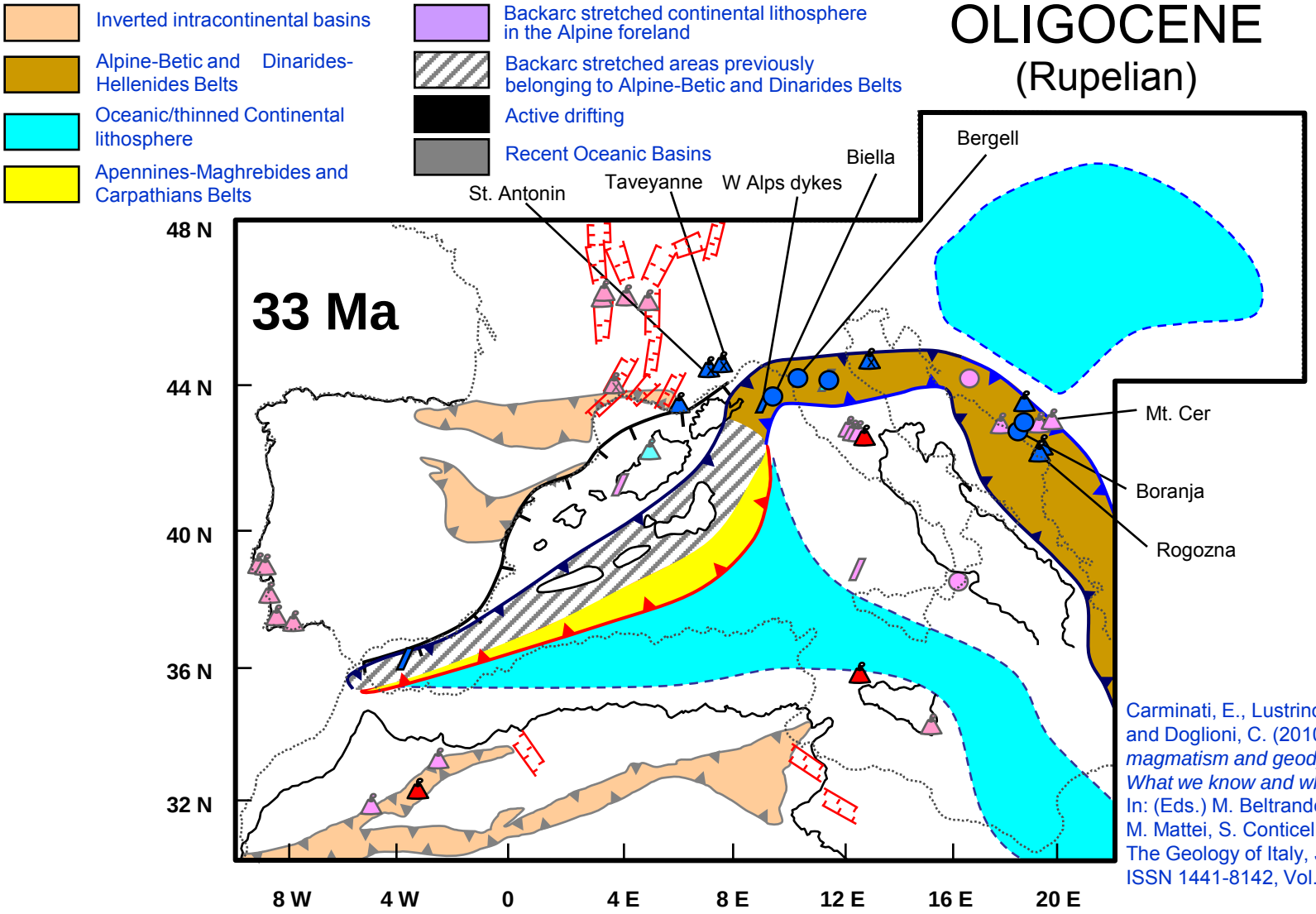
OLIGOCENE
(Rupelian)



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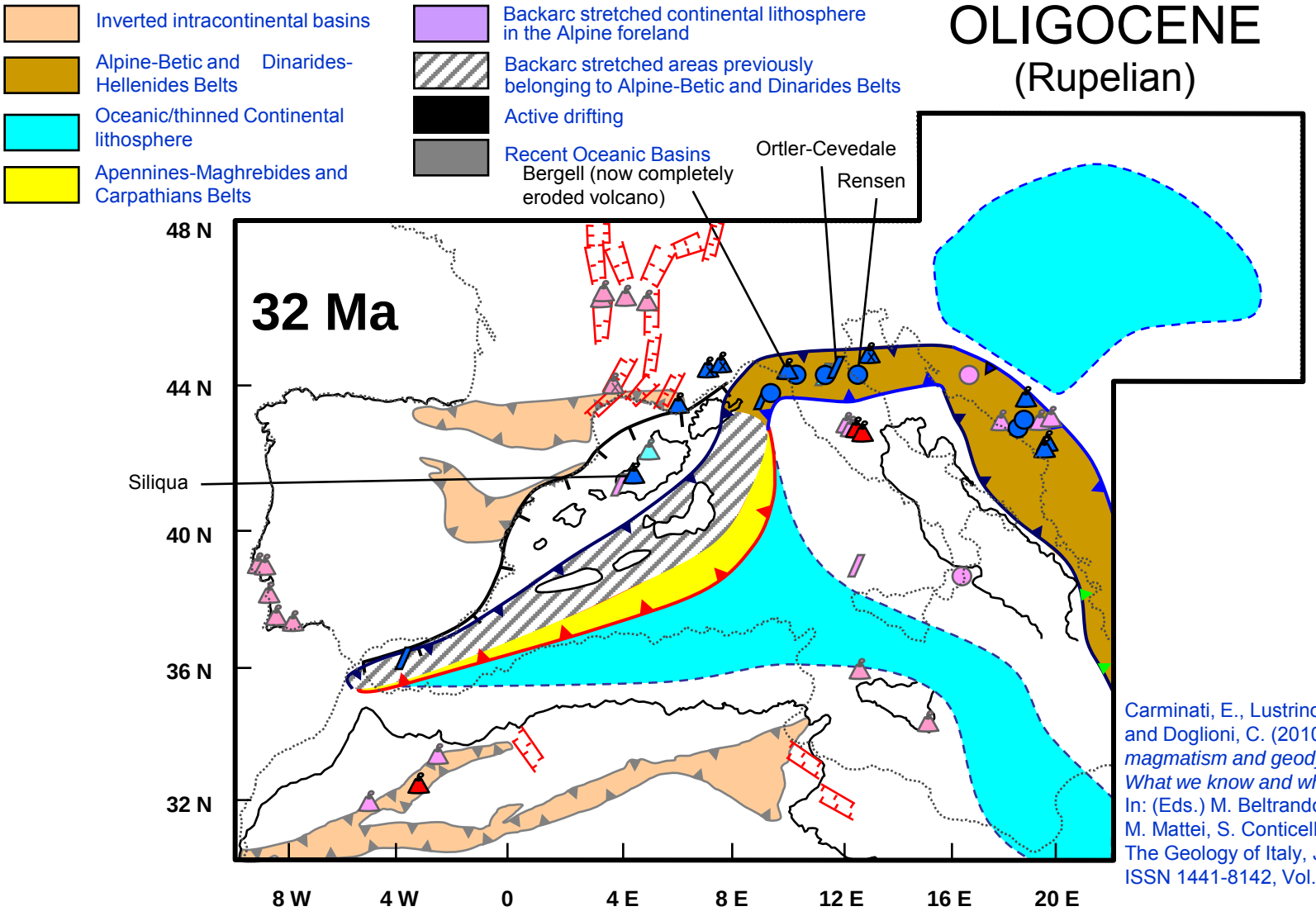
Peak of igneous activity in the Alps starts. Abundant subduction-related igneous activity also in the Dinarides. Subduction-related volcanic activity in Provence and Alpine foreland. Atlas stops growing.

OLIGOCENE
(Rupelian)



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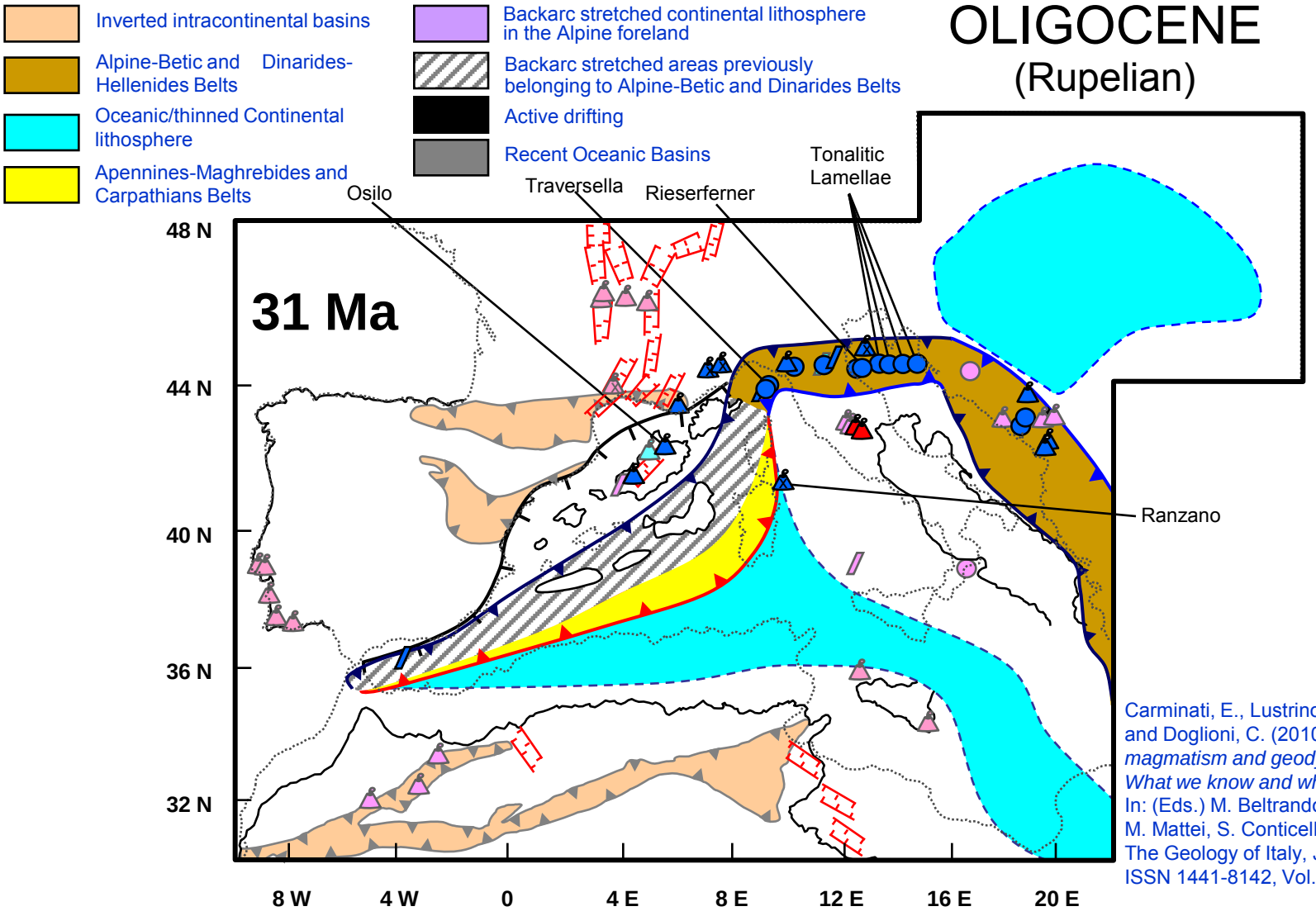
(Rupelian)



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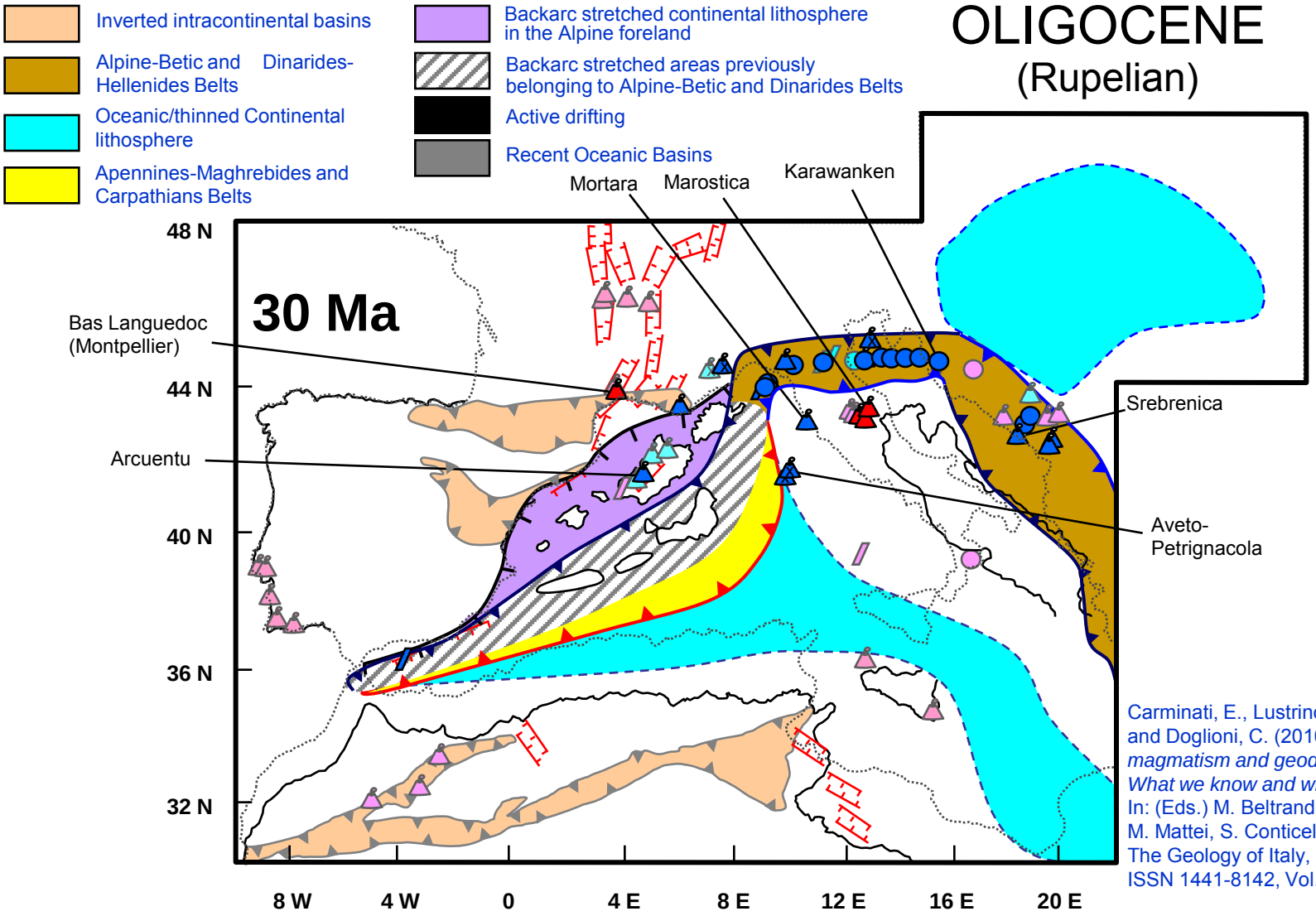

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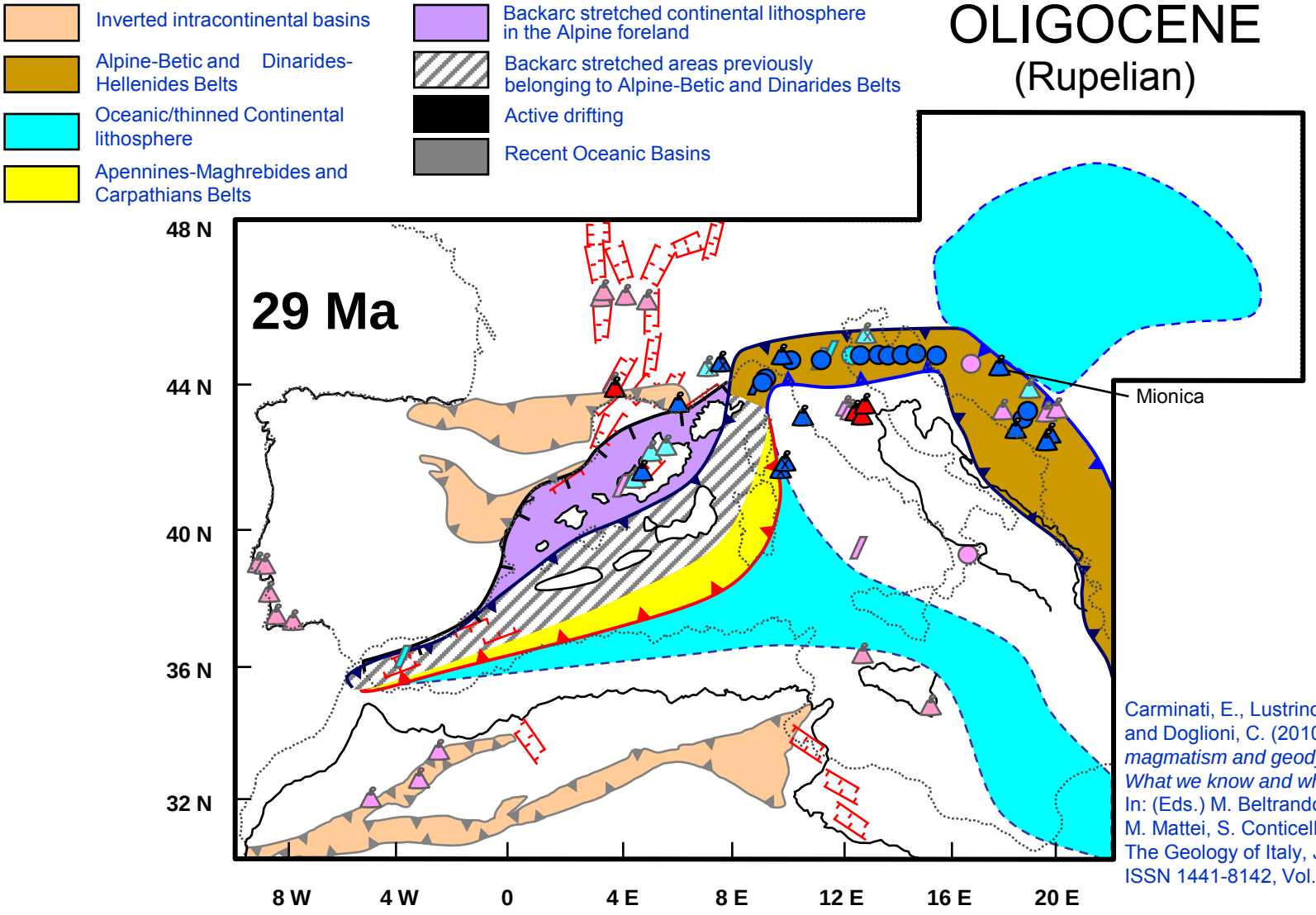
The lithosphere in the embryonic Ligurian-Provençal Basin is thinned. Anomalous/unclear position of subduction-related volcanism at Mortara and Aveto-Petrignacola.

OLIGOCENE
(Rupelian)



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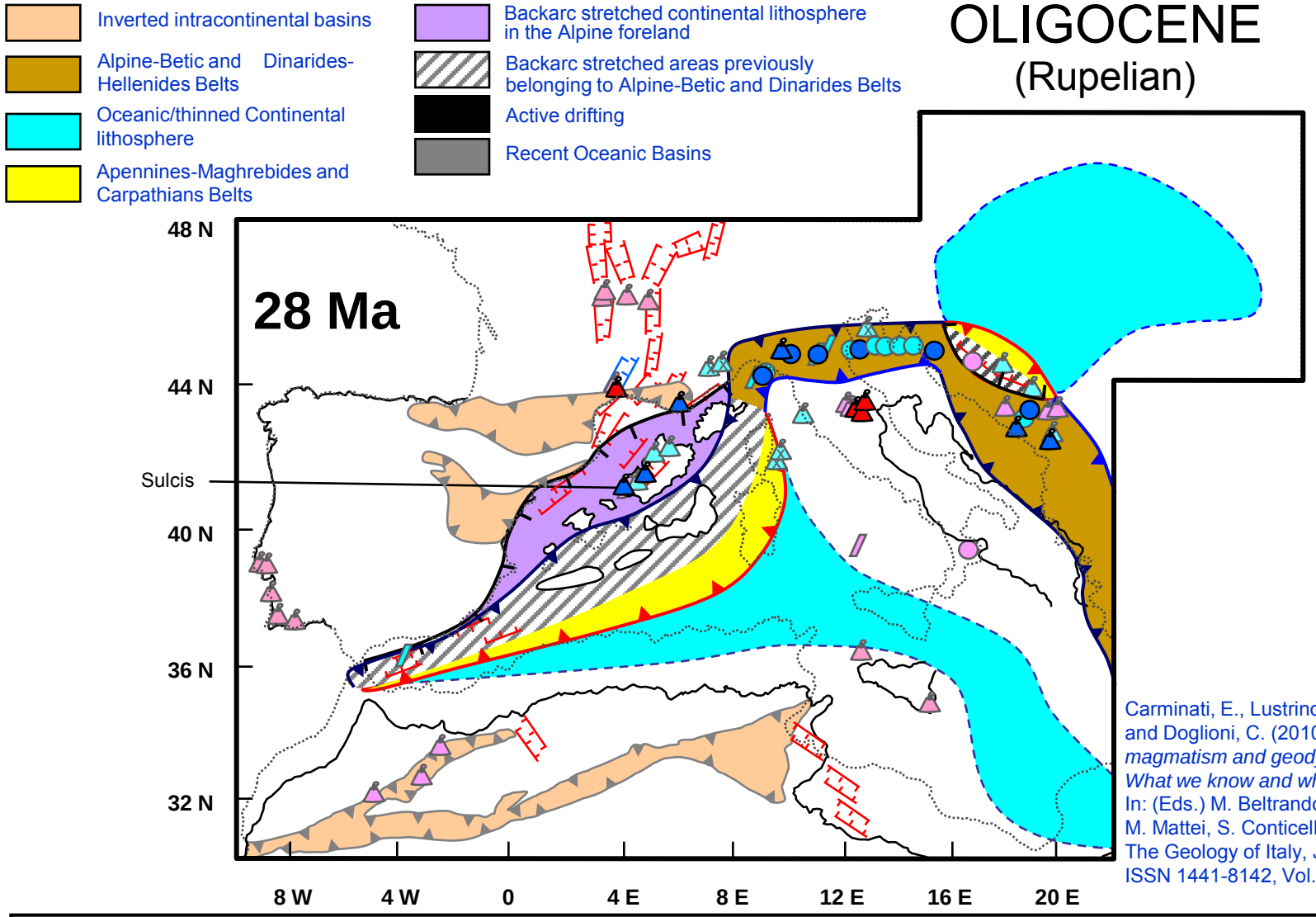
(Rupelian)



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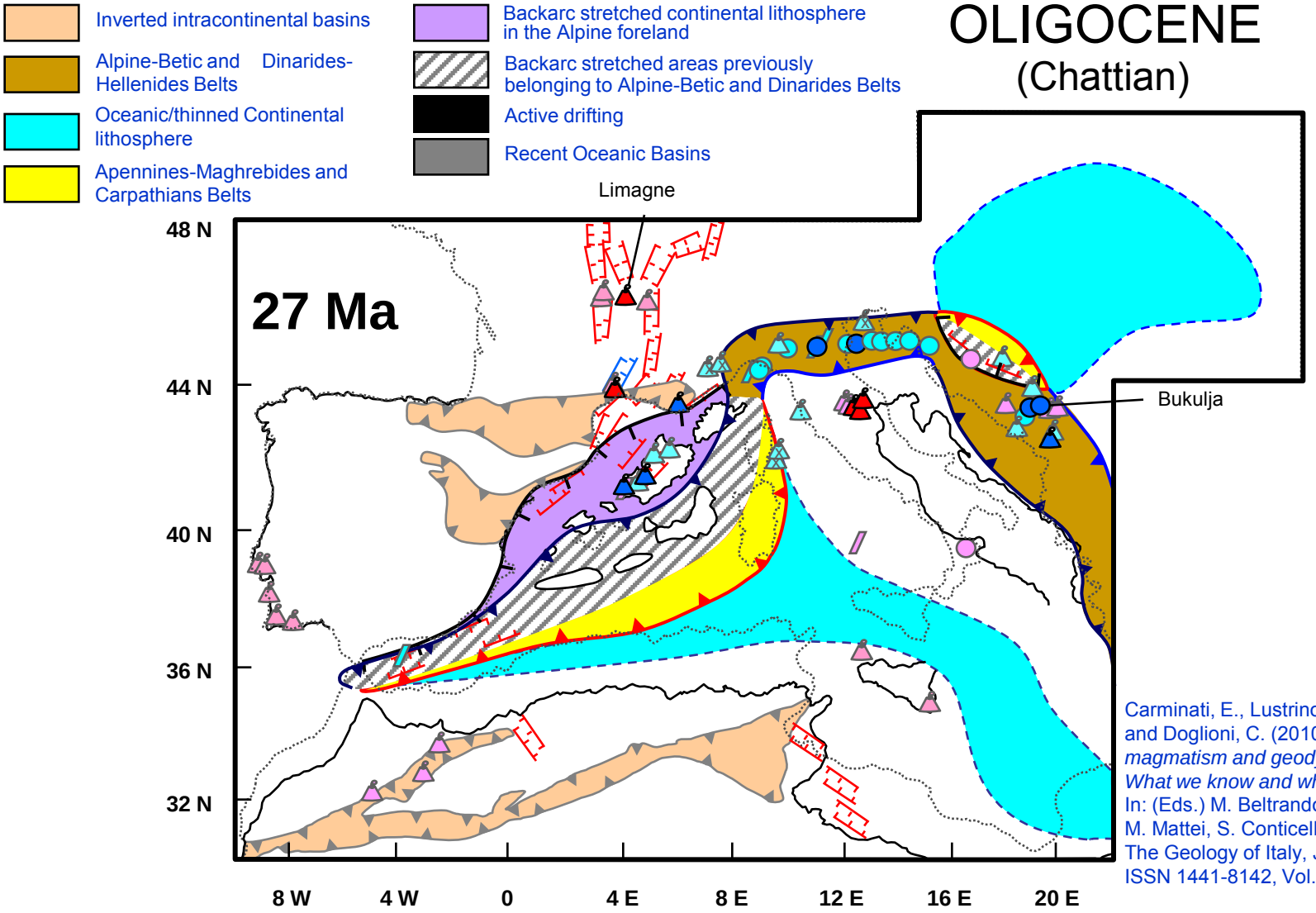
The Carpathians accretionary prism develops along the retrobelt of the Dinarides where oceanic or thinned continental lithosphere occurs. Stretching affects Sardinia-Corsica and Balearic Islands. The Apennines-Maghrebides arc increases its curvature, being bounded by continental lithosphere to the N and to the S.

OLIGOCENE
(Chattian)



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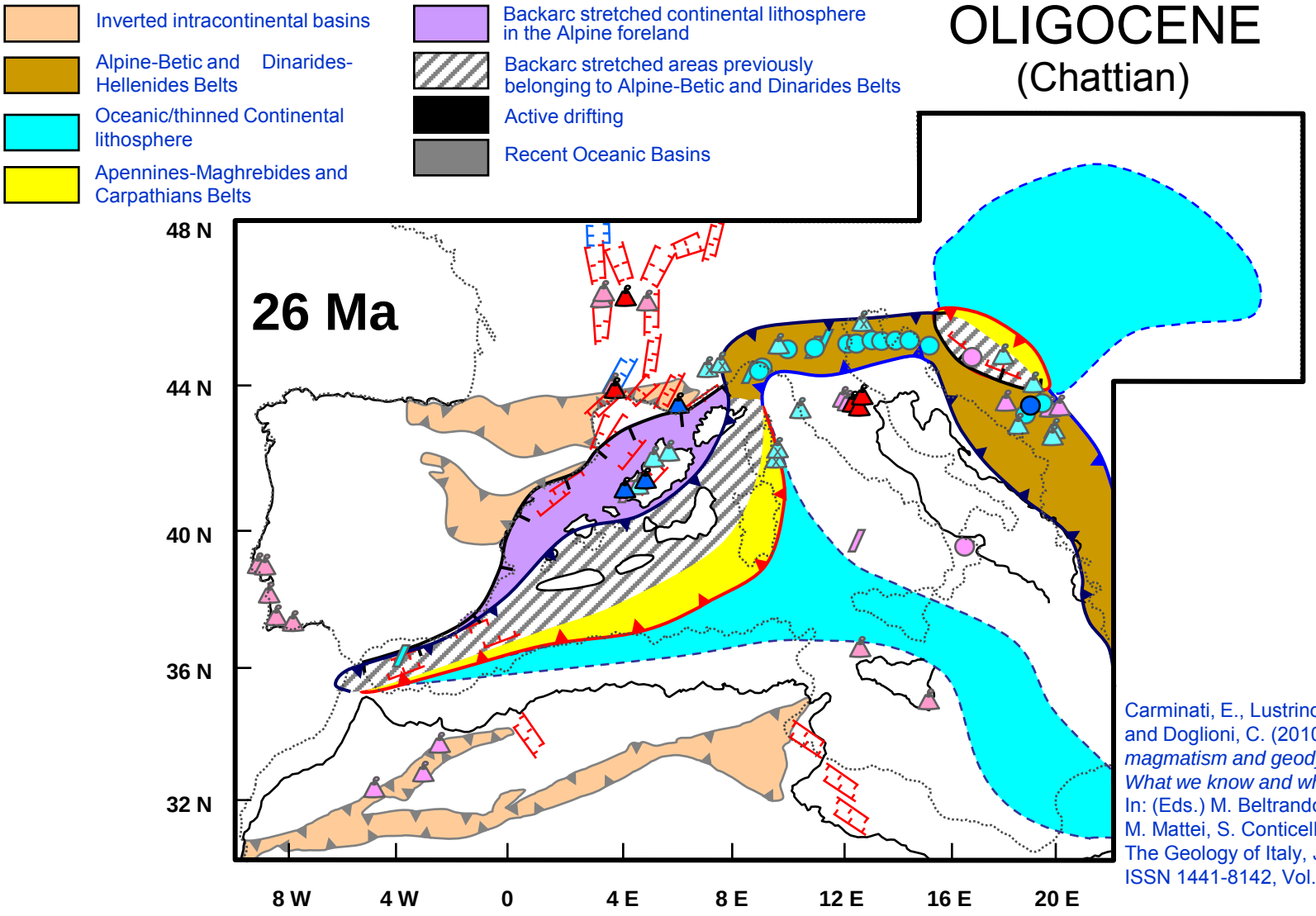
Igneous activity in the Alps strongly decreases. Subduction-related volcanic activity in Sardinia is fully developing. Clockwise rotation of the Balearic Promontory is due to intra-continental rifting in the Valencia Trough.

OLIGOCENE
(Chattian)



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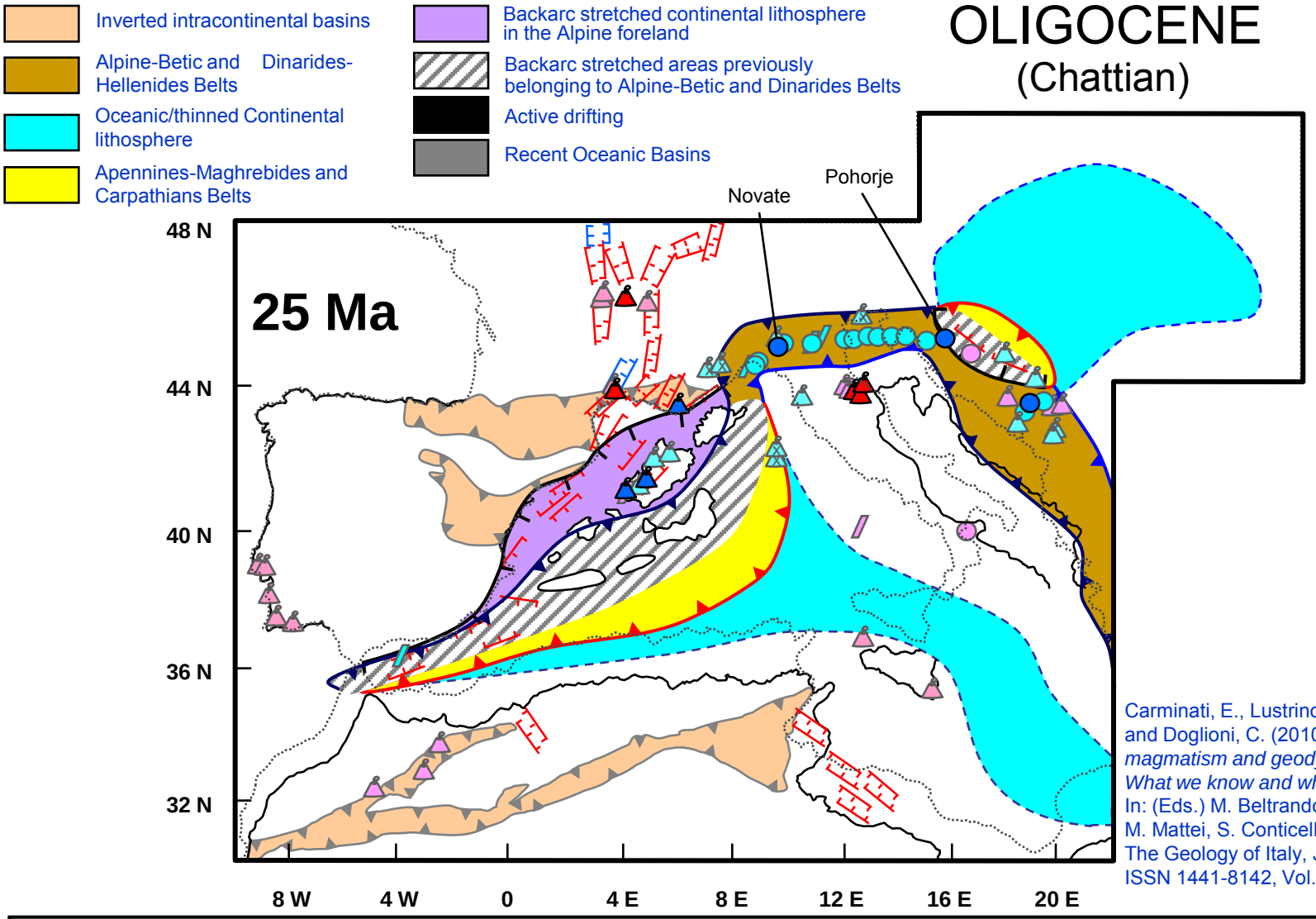
(Chattian)



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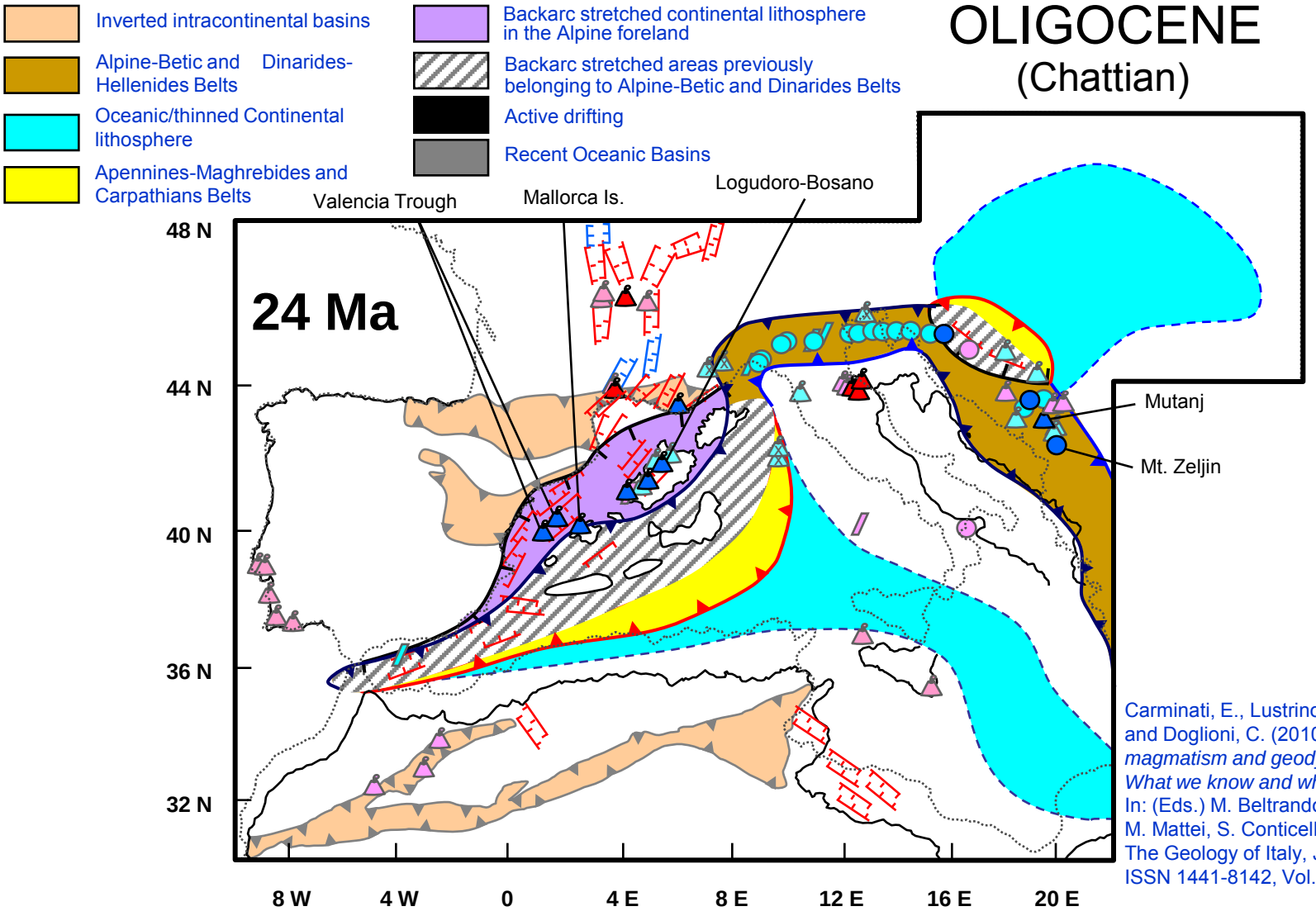
The Pyrenees stop growing. Major exhumation stage in the Lepontine Dome in Central Alps. The Taveyanne volcaniclastics are probably trapped in the Apine thrusts.

OLIGOCENE
(Chattian)



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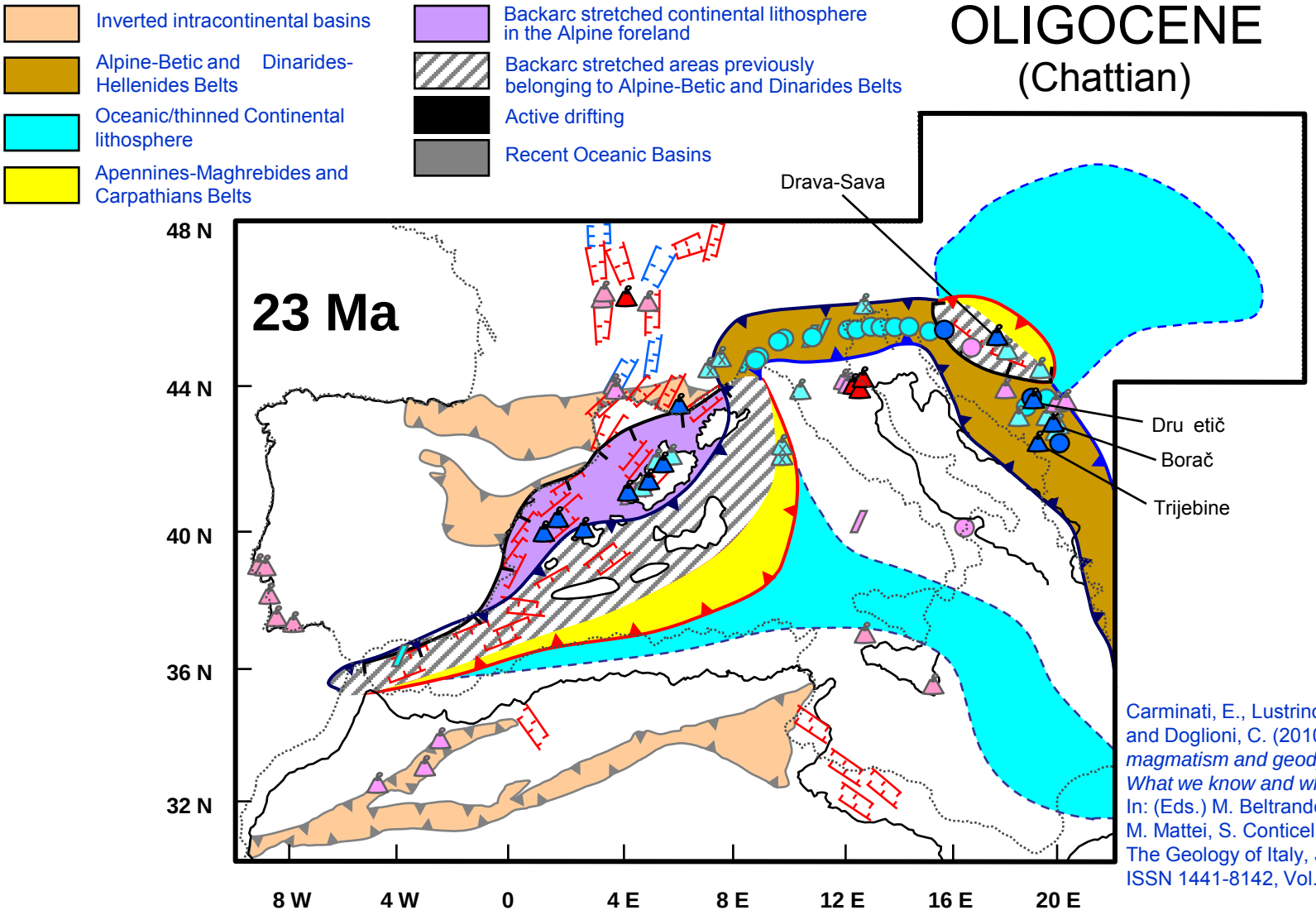
OLIGOCENE
(Chattian)



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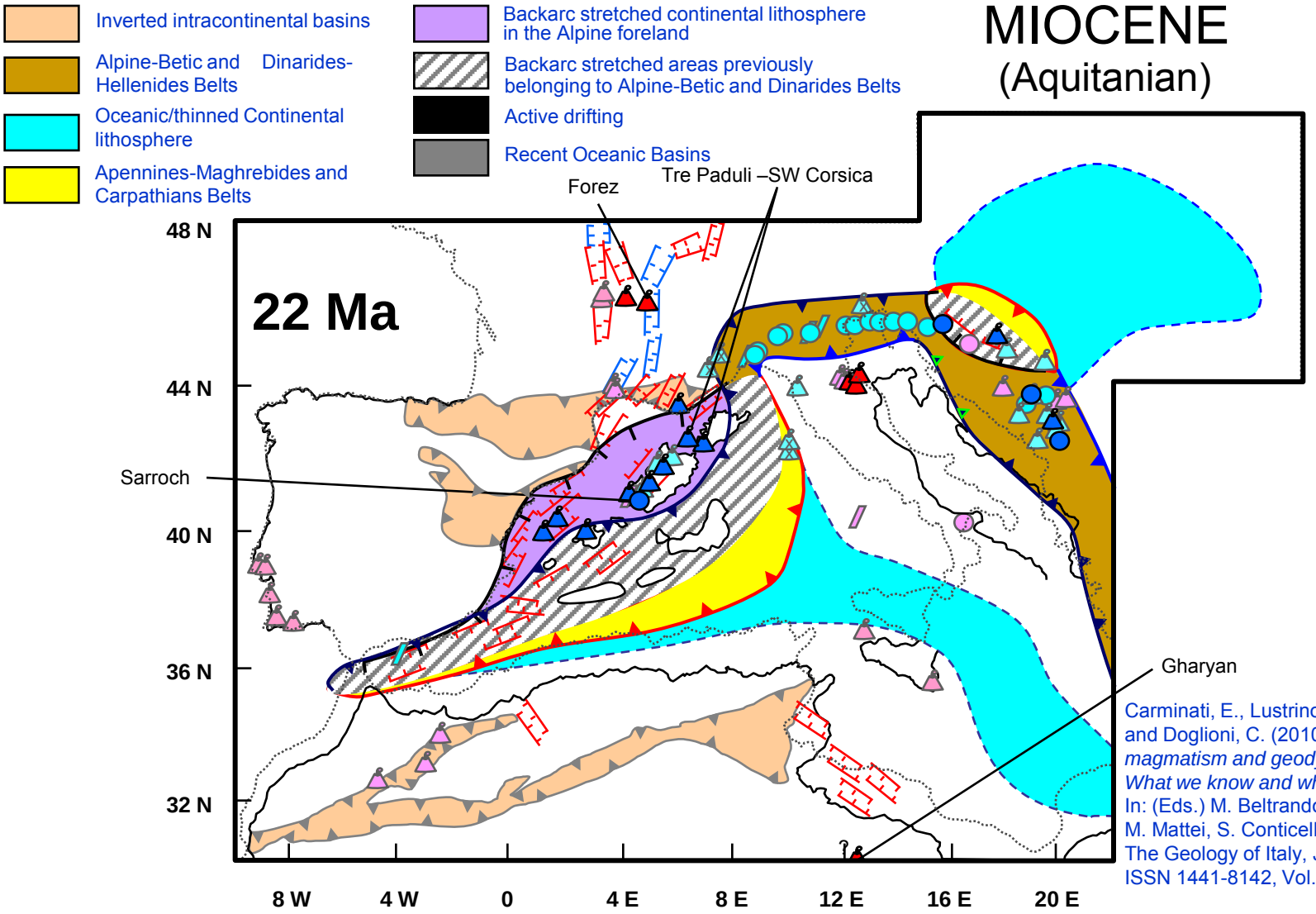
First episodes of subduction-related igneous activity in the Carpathian system. Consumption of relict Alpine Tethys in N Apennines.

MIOCENE
(Aquitanian)



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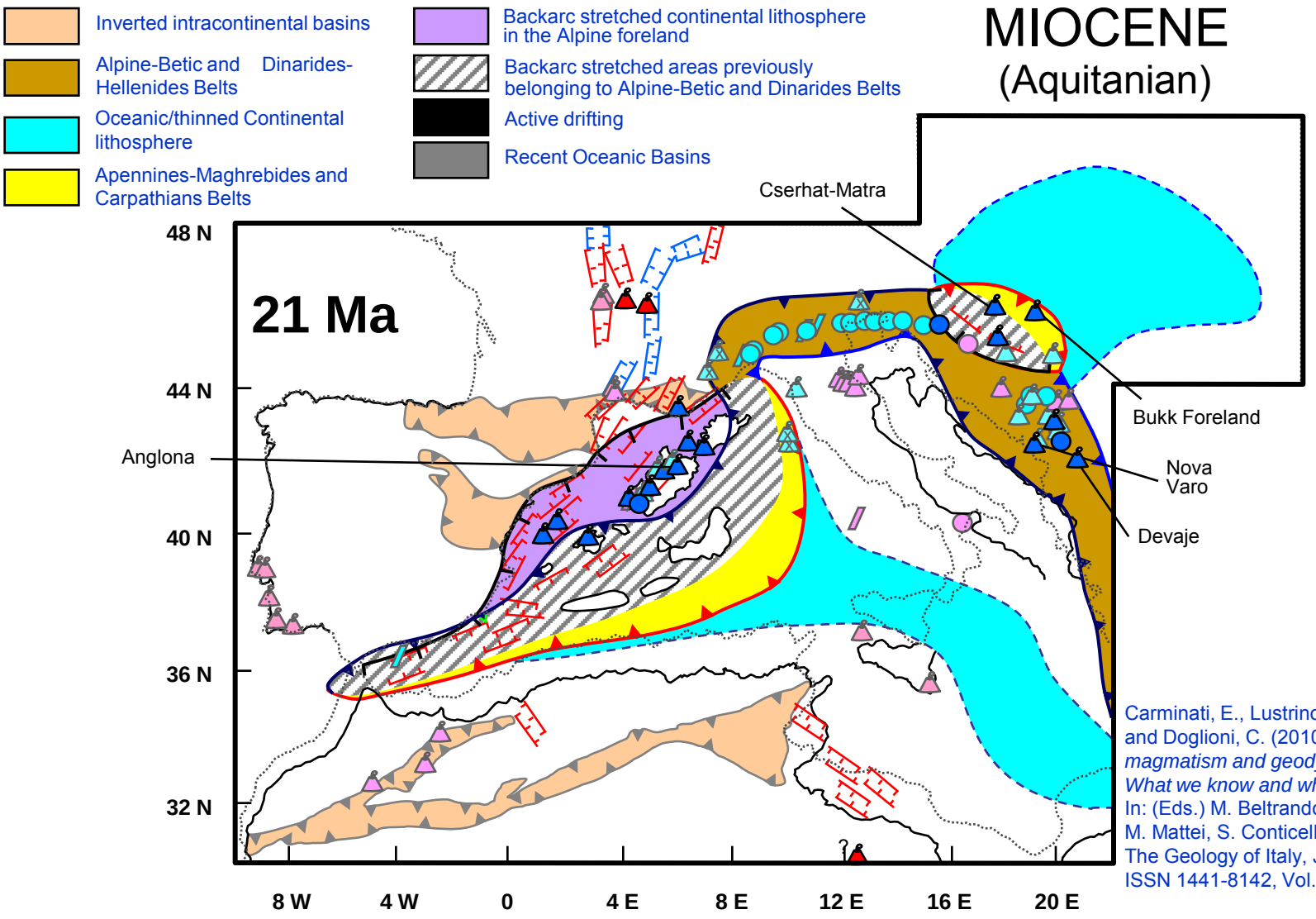
The peak of igneous activity in Sardinia begins.



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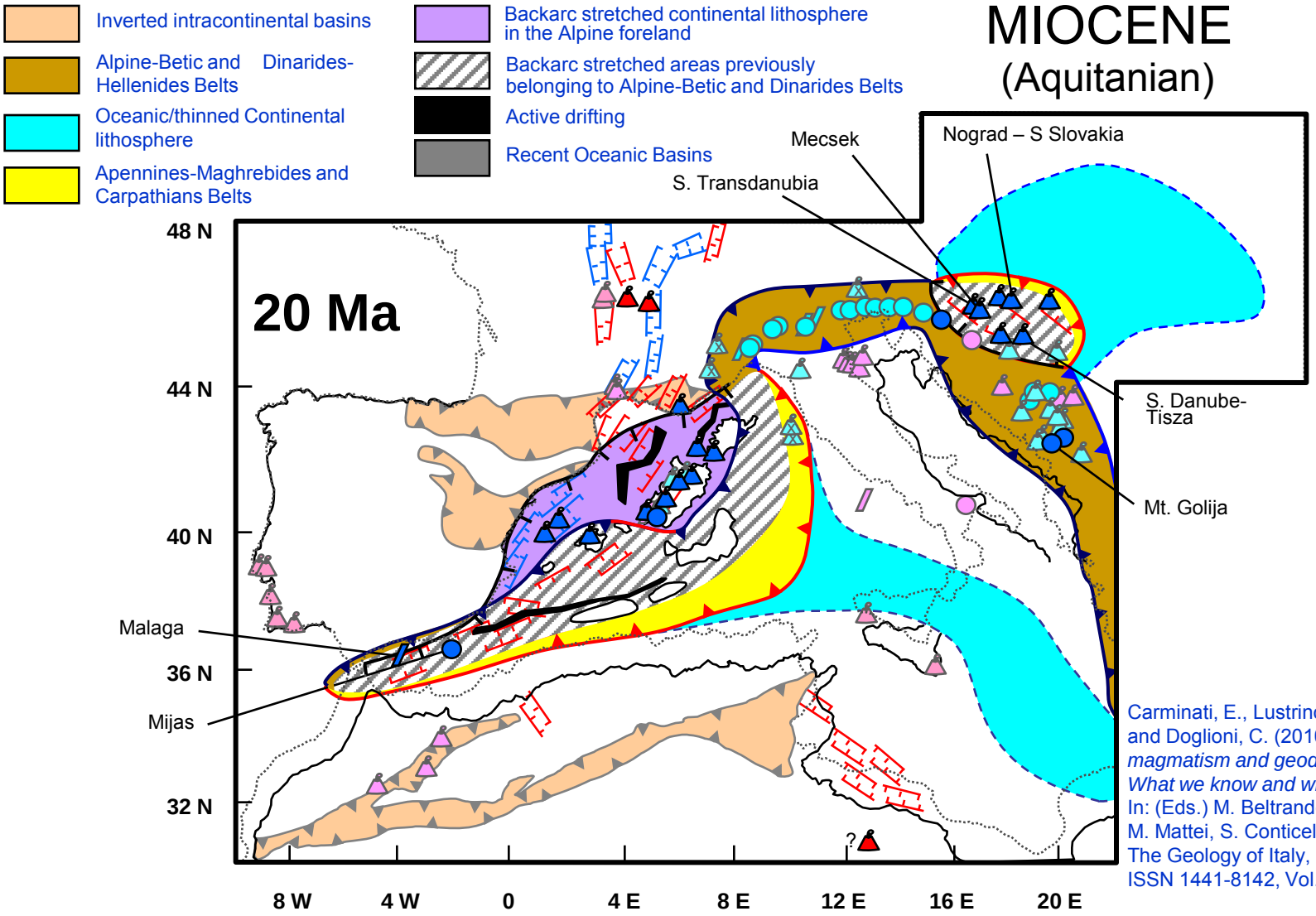
MIOCENE
(Aquitanian)



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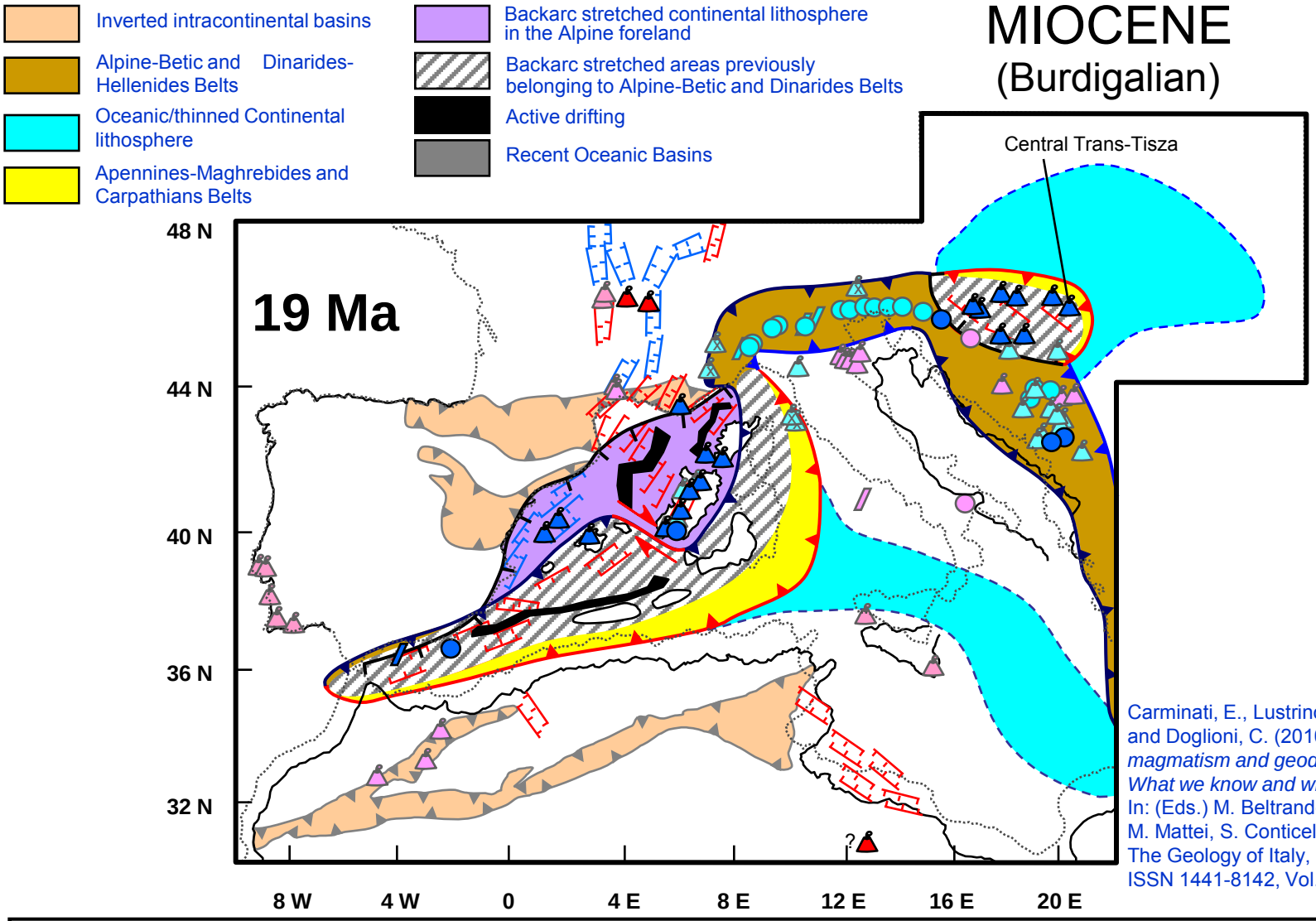
Beginning of spreading in the Apennines-Maghrebides back-arc. Inset of counter-clockwise rotation of Sardinia-Corsica. Acme of igneous activity in Sardinia. Subduction-related volcanic activity starts in the Betics. Back-arc stretching in the embryonic Pannonian Basin.

MIOCENE
(Burdigalian)



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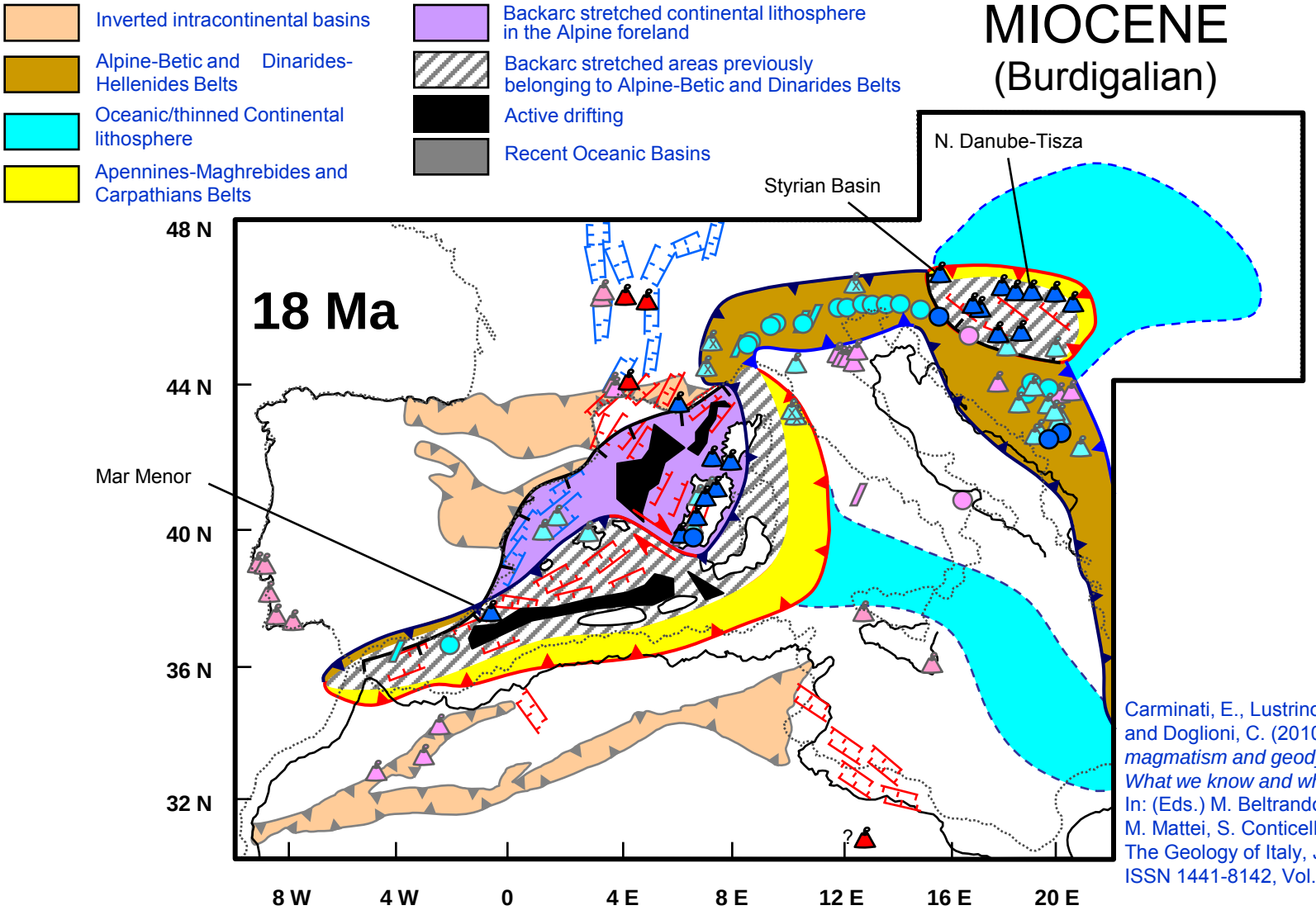
Fast counter-clockwise rotation of Sardinia-Corsica.

MIOCENE
(Burdigalian)



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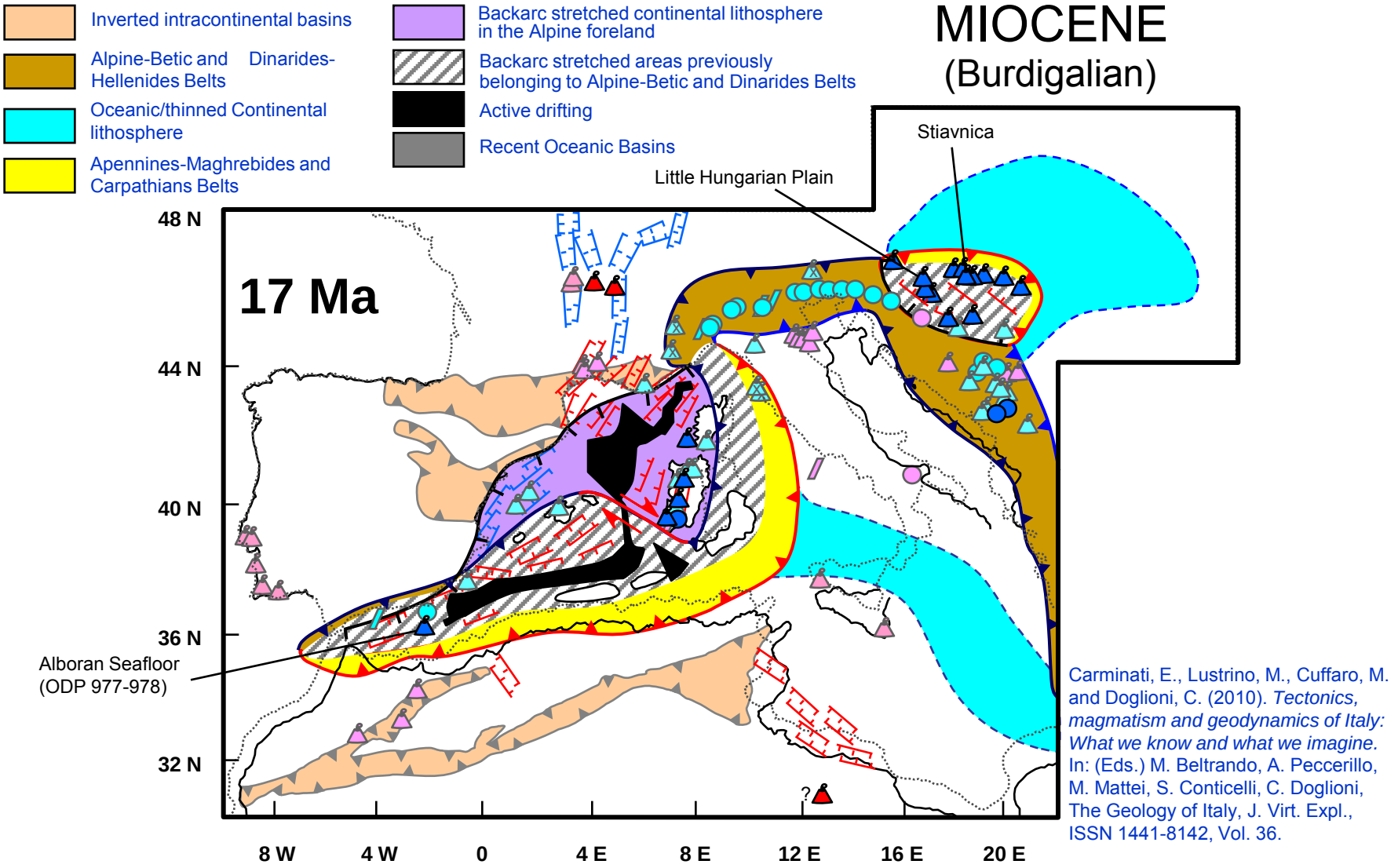
MIOCENE
(Burdigalian)



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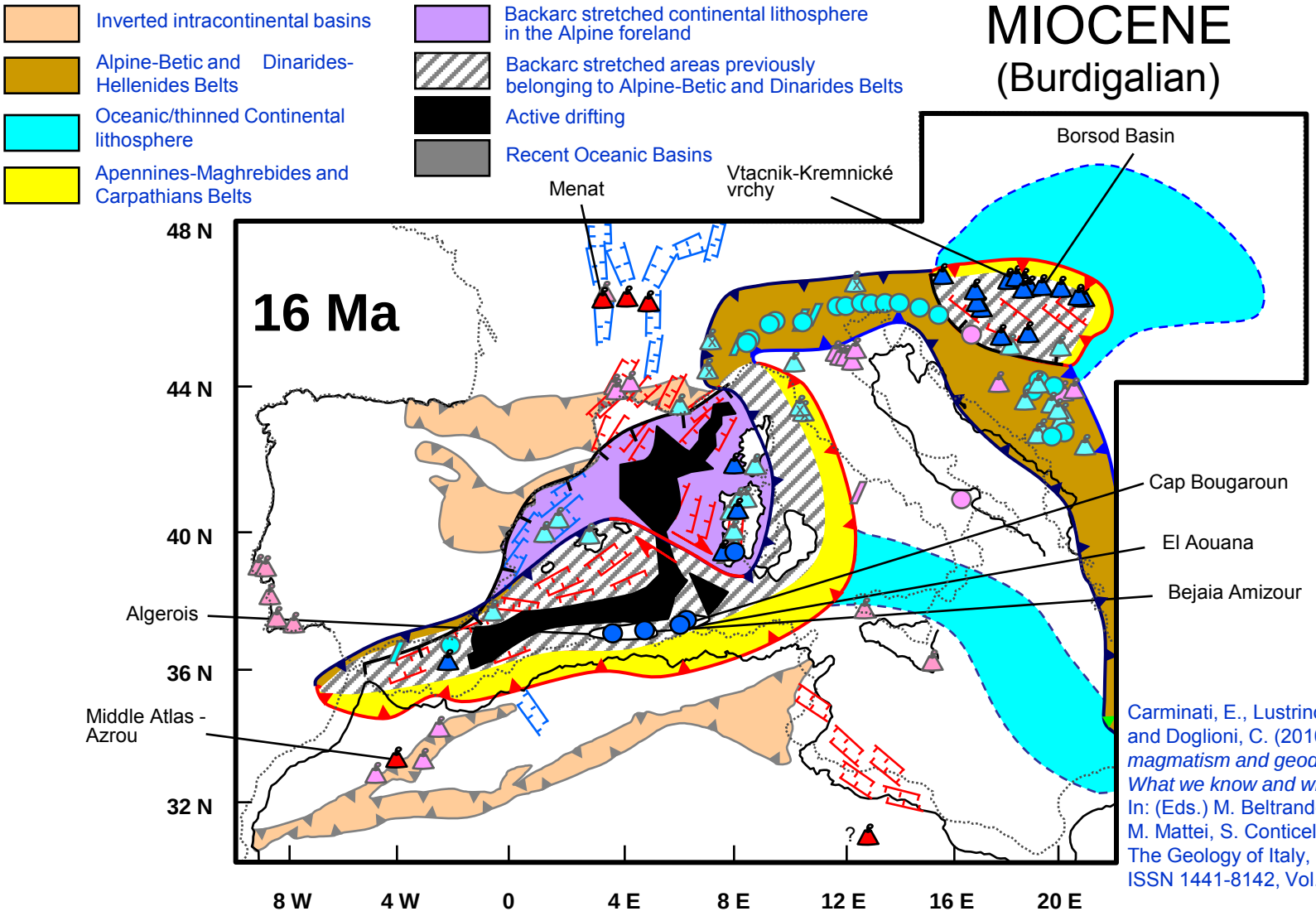
Gradual closure of the Indian Ocean-Atlantic Ocean connection. Monterey Carbon Isotope Excursion in Central Mediterranean begins (~17-13.5 Ma).

MIOCENE
(Burdigalian)



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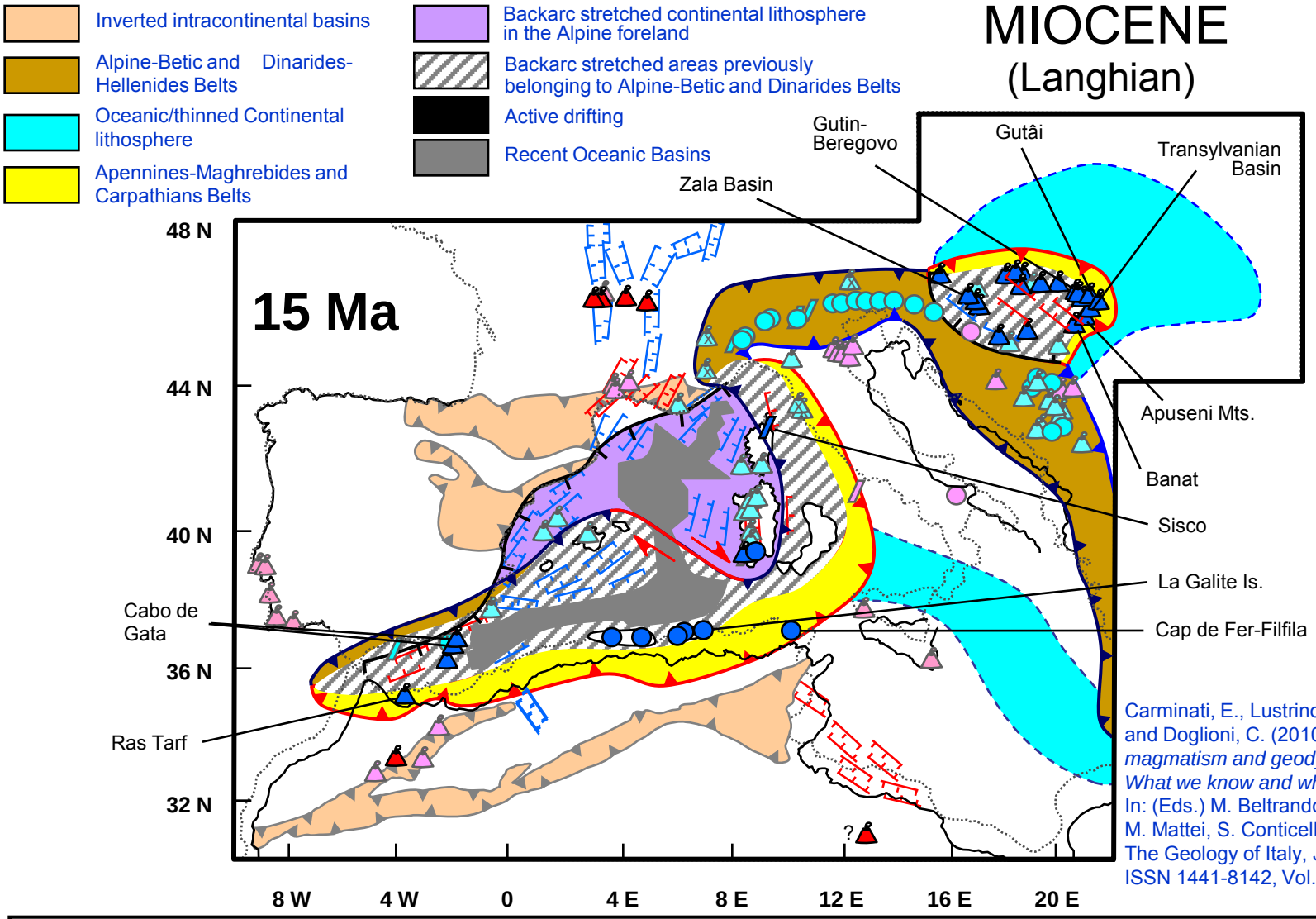
Possible docking of the Apennines-Maghrebides prism with Adria and Africa continental lithospheres. Subduction-related igneous activity in the Kabilies. Iberian Chain stops growing.

MIOCENE
(Langhian)



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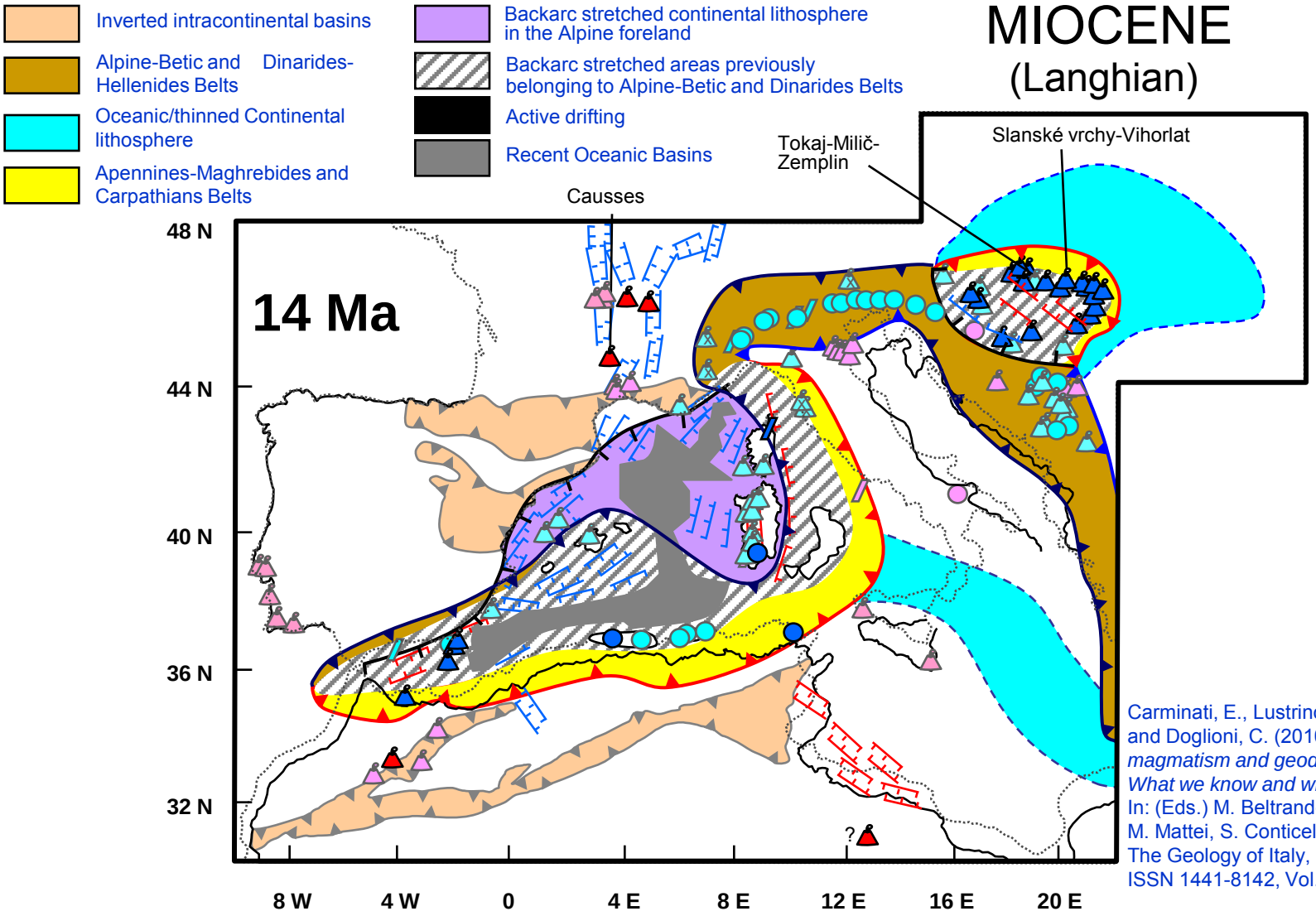
Sardinia-Corsica block rotation stops. Calabria and Peloritani Mts. still attached to Sardinia-Corsica plate. First subduction-related volcanic activity in the embryonic Tyrrhenian Sea at Sisco. No substantial tectonic modifications in the embryonic Tyrrhenian Sea until 10 Ma. Numidian sand event in the southern Apennines.

MIOCENE
(Langhian)



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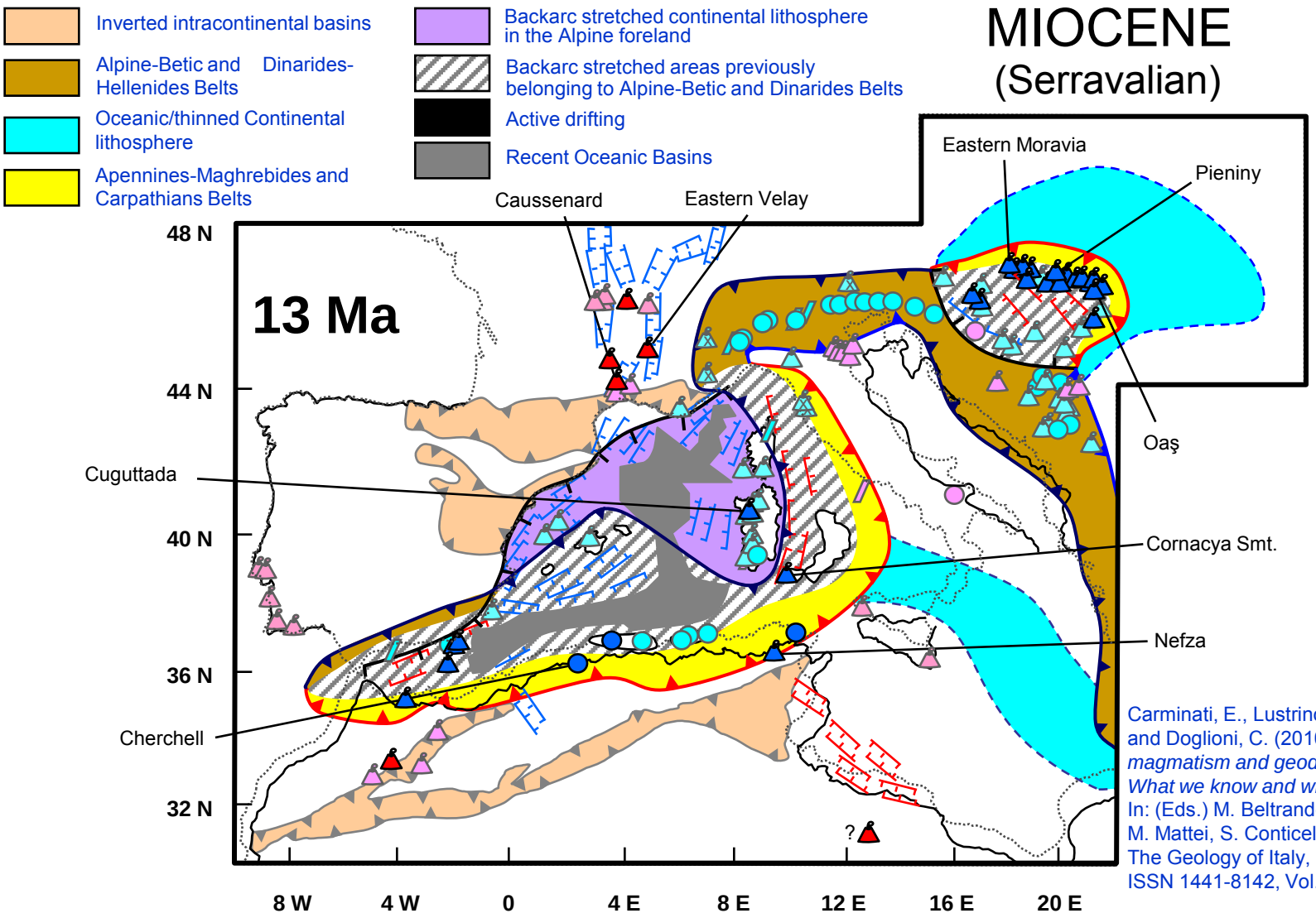
Volcanic activity increases in the Betics, Rif and Alboran Sea.



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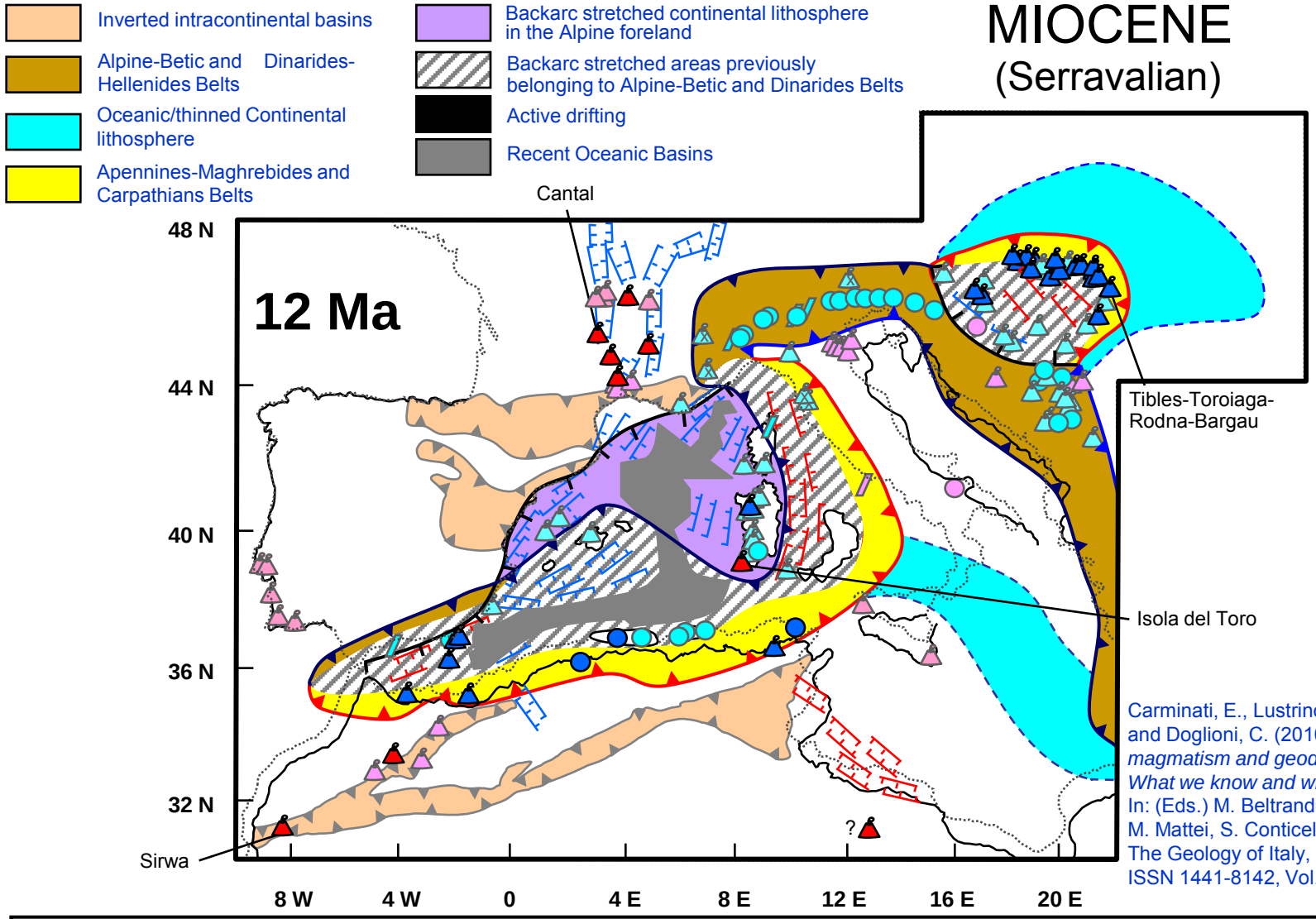
MIOCENE
(Serravalian)



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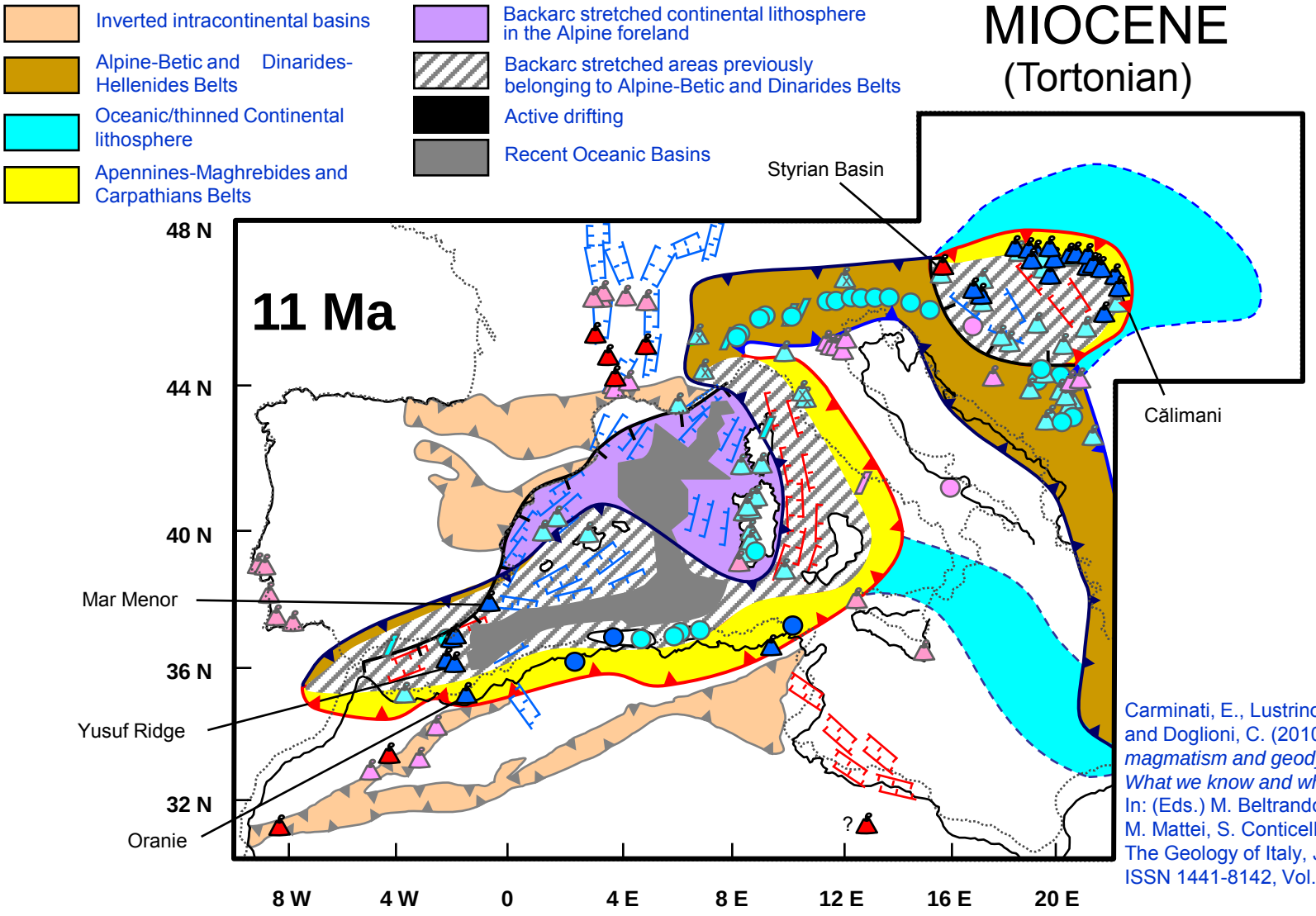
Subduction-related igneous activity in Sardinia stops. First “anorogenic” igneous activity in Sardinia. Calabria and Peloritani Mts. begin to separate from Sardinia-Corsica block.

MIOCENE
(Tortonian)



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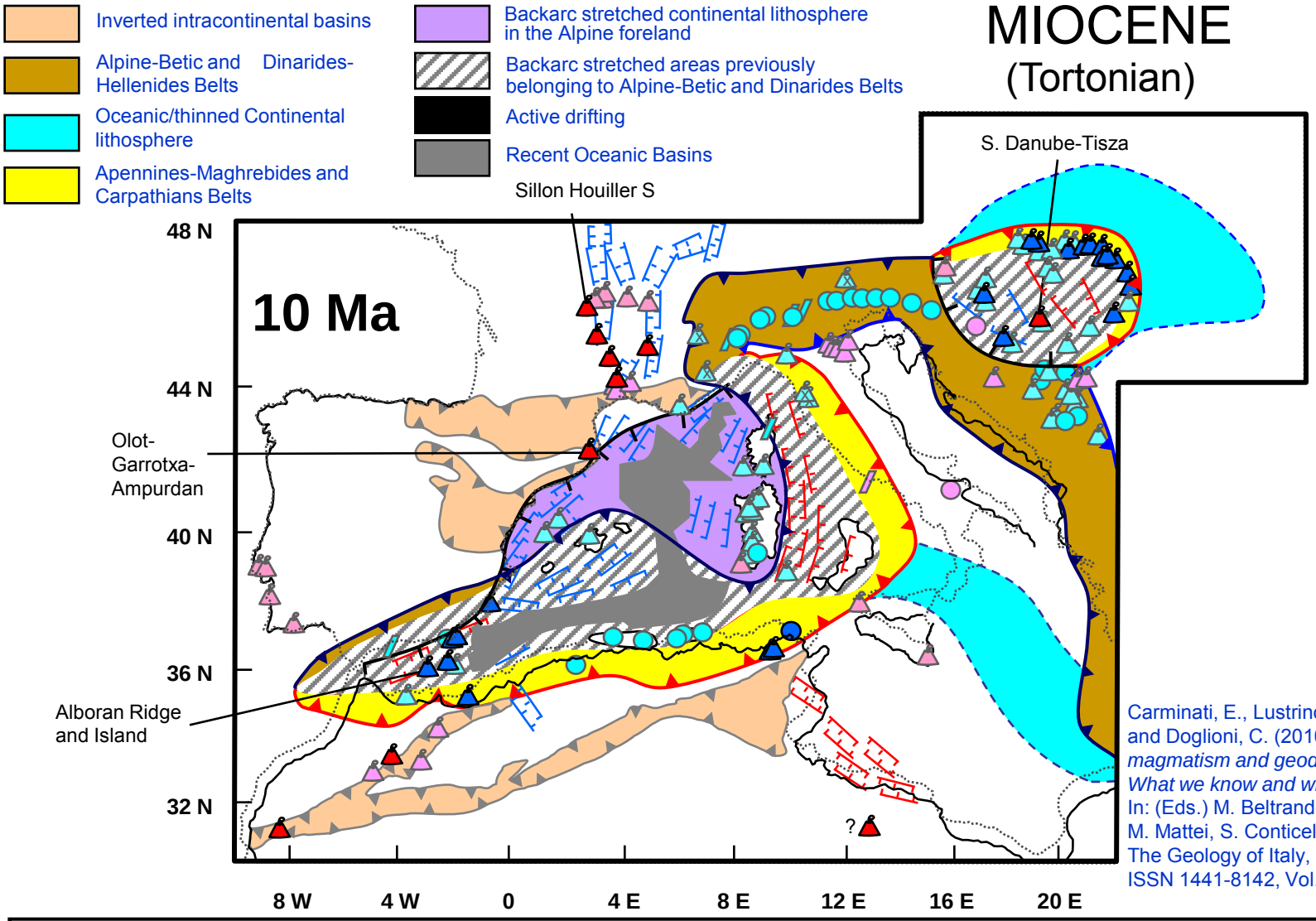
MIOCENE
(Tortonian)



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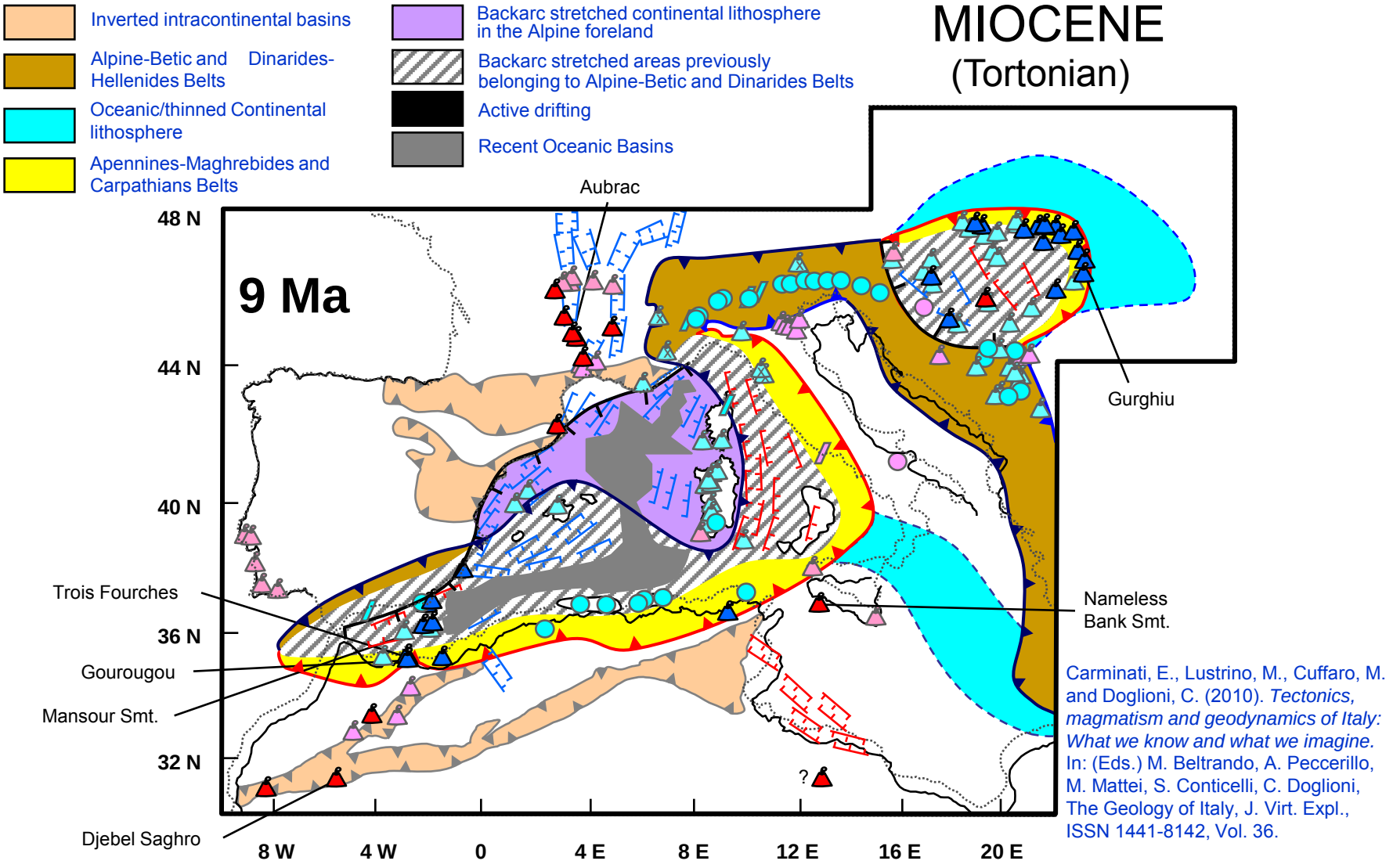
Important igneous activity in the French Massif Central.

MIOCENE
(Tortonian)



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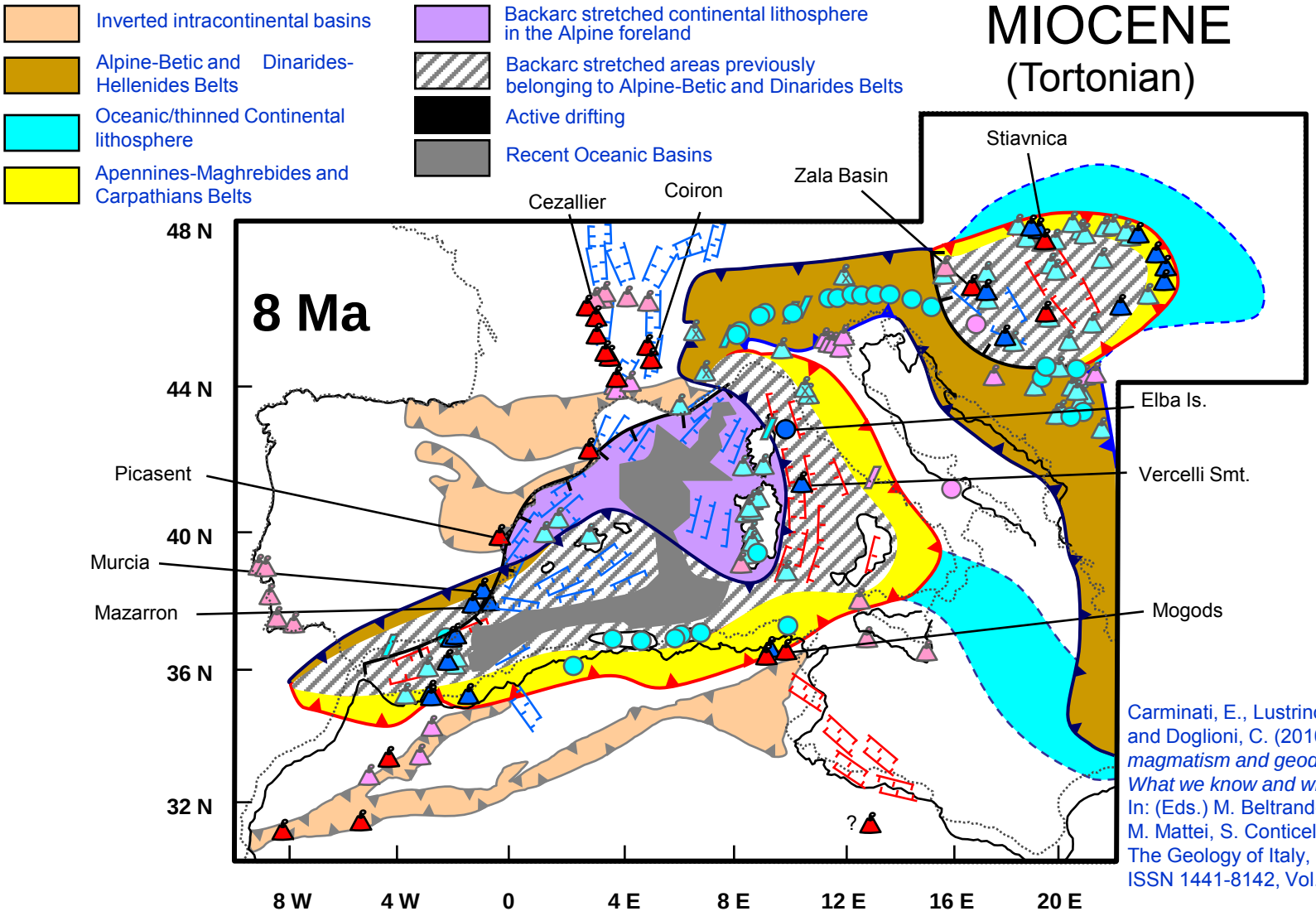
MIOCENE
(Tortonian)



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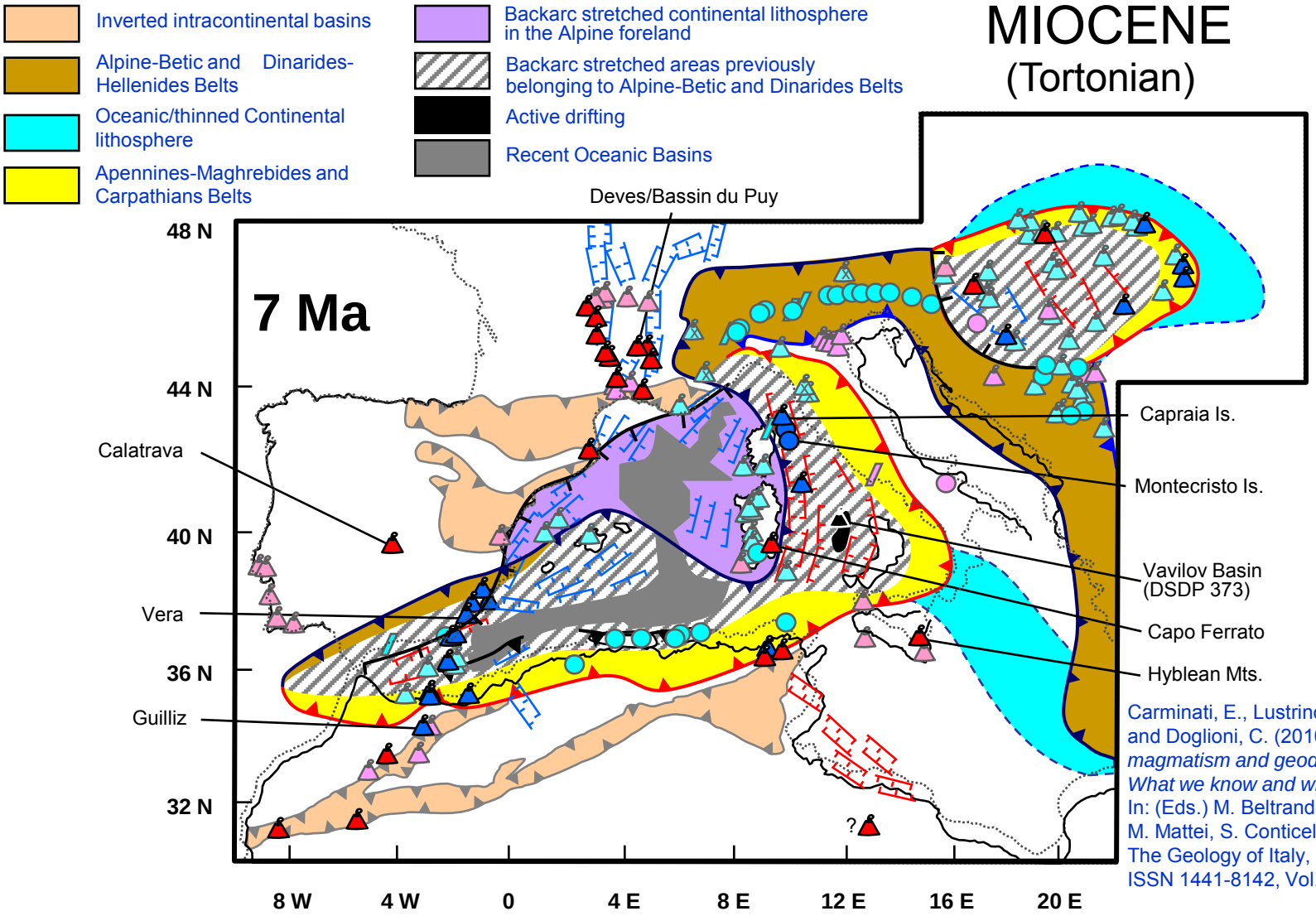
Important subduction-related igneous activity in the embryonic Tyrrhenian Sea begins. “Anorogenic” magmatism post-dates subduction-related magmatism in the Valencia Gulf and Tunisian Tell.

MIOCENE
(Tortonian)



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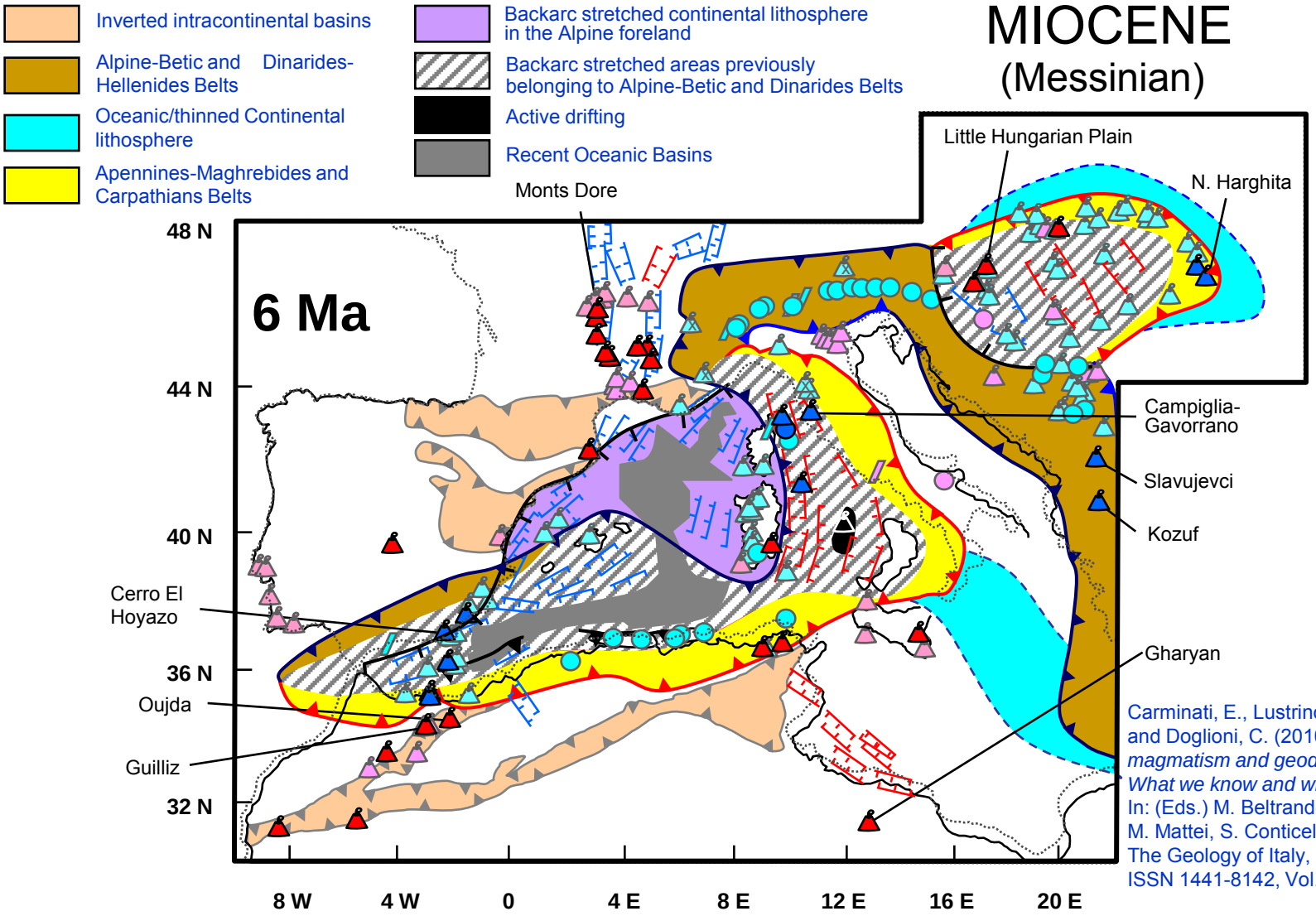
Peak of igneous activity in the Betics-Rif-Alboran area. First evidences of oceanization in the Tyrrhenian Sea.

MIOCENE
(Messinian)



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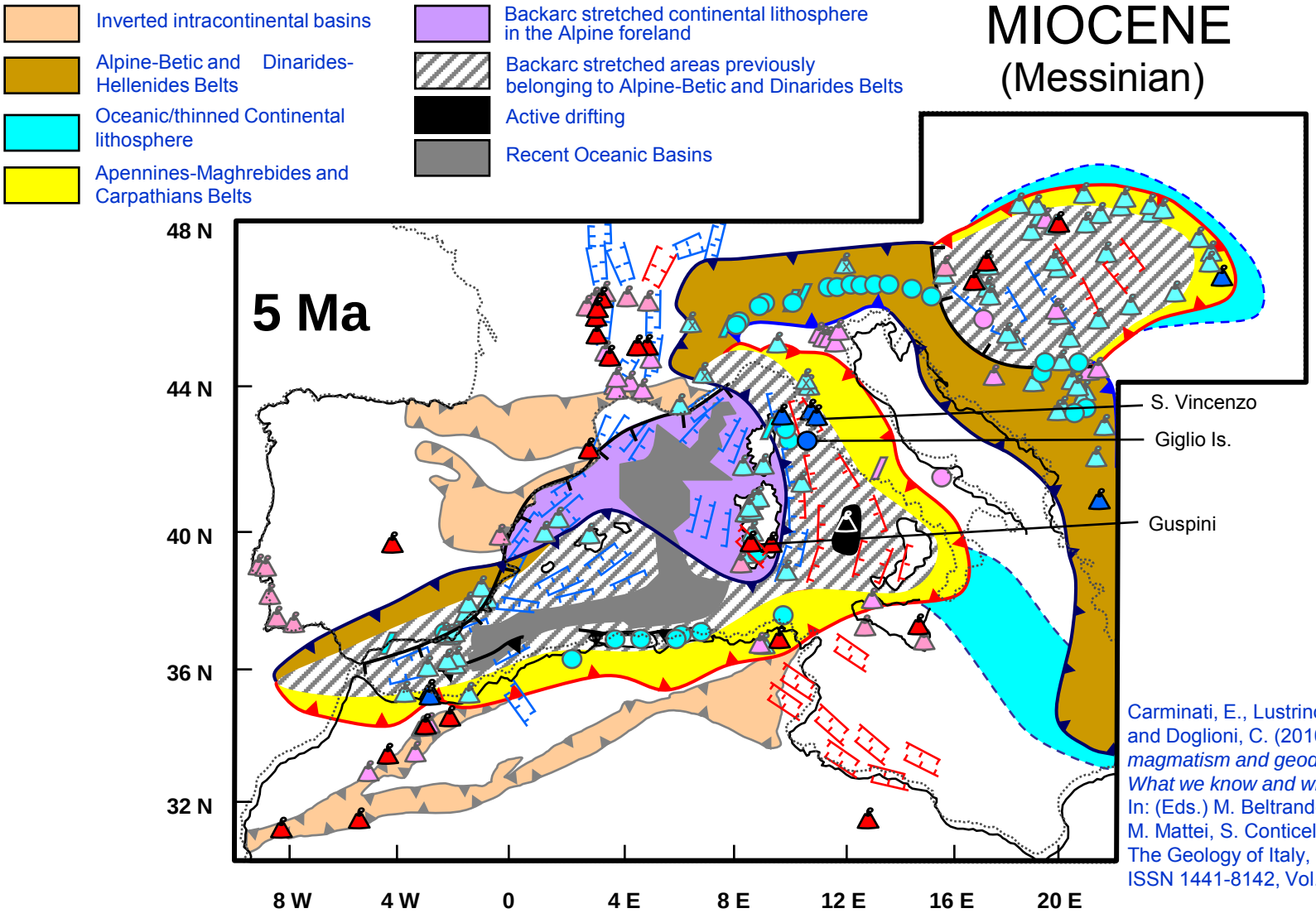
Development of the Tuscan Magmatic Province. Messinian salinity crisis. Full development of the Moroccan Hot Line.

MIOCENE
(Messinian)



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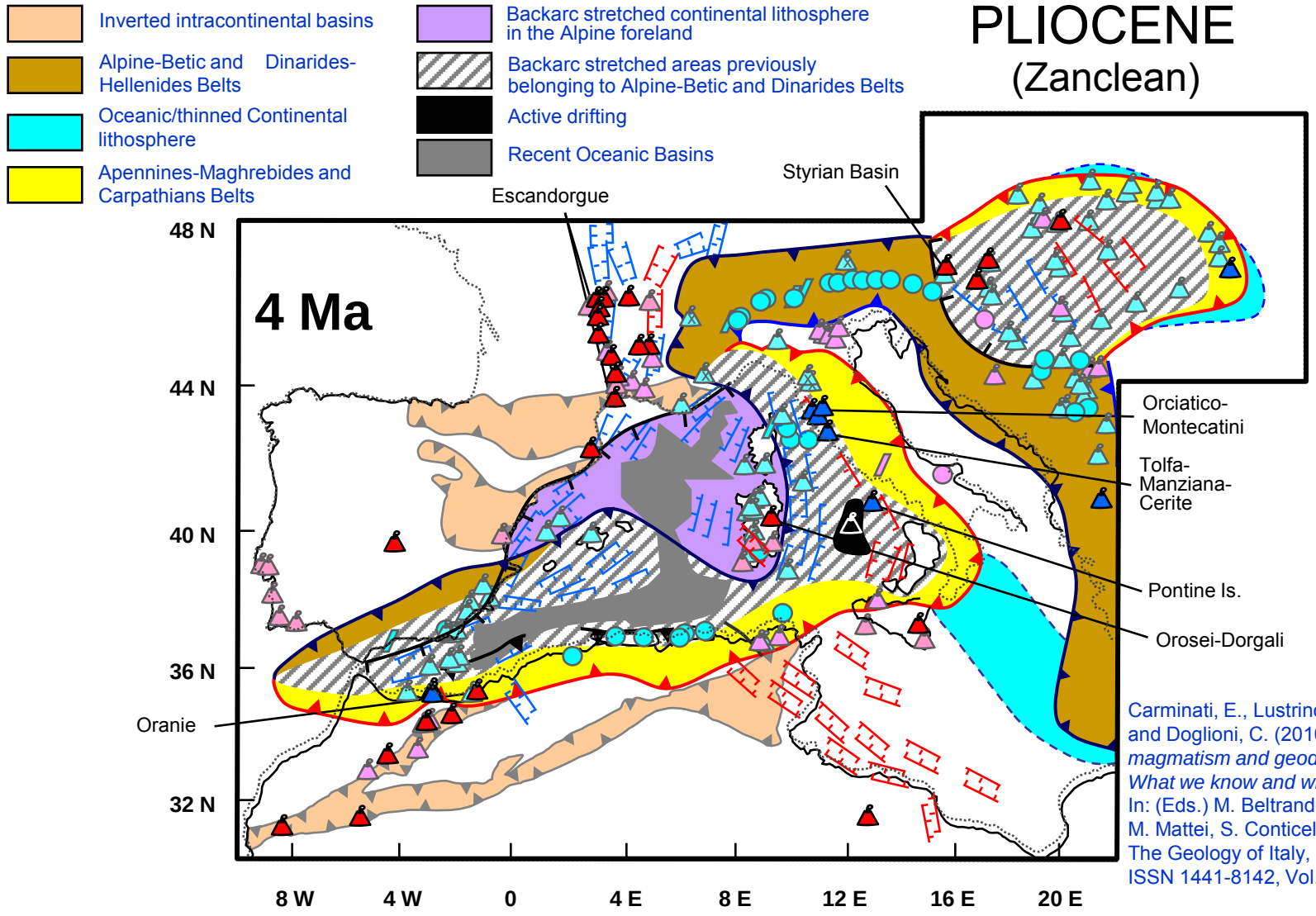
PLIOCENE
(Zanclean)



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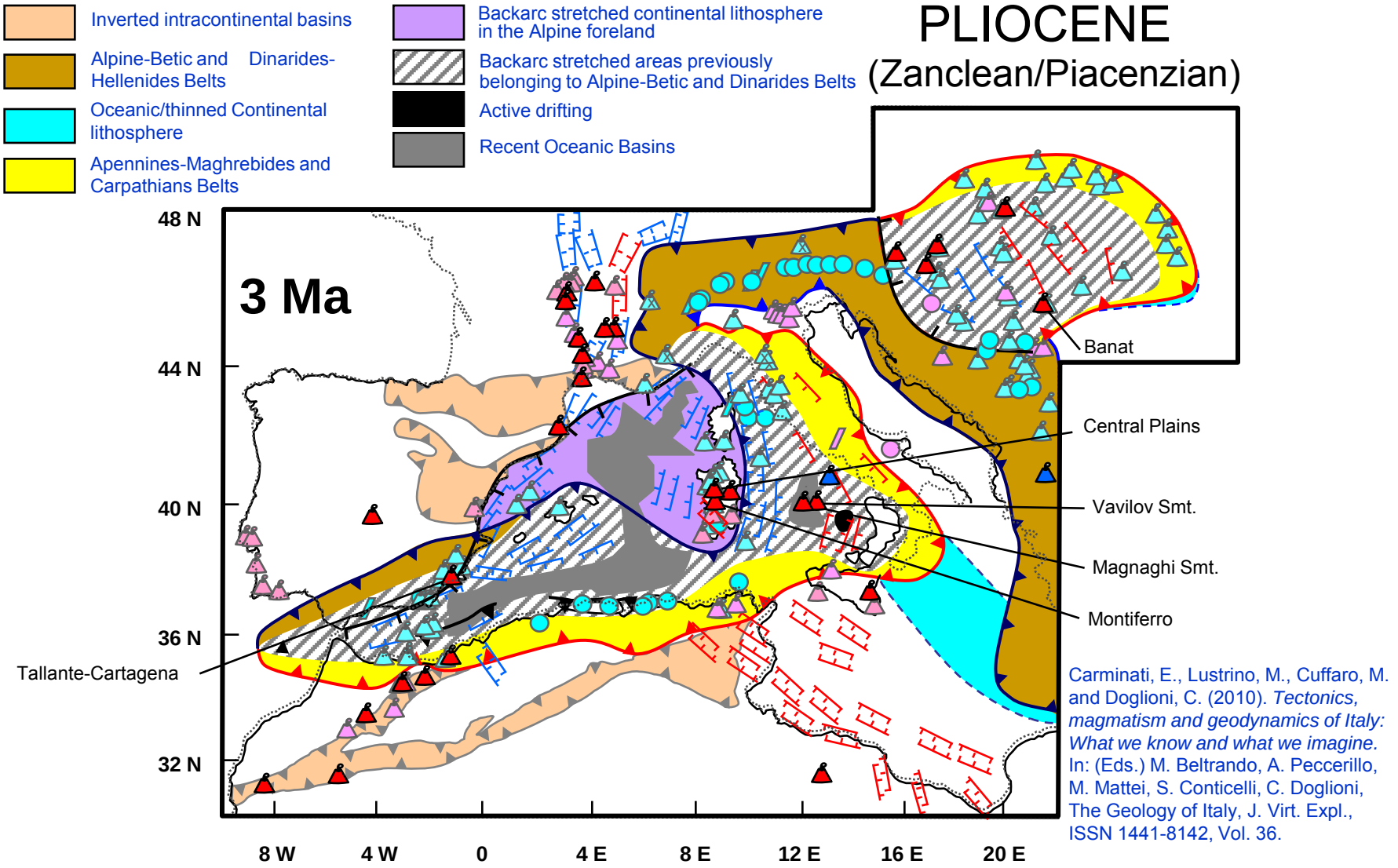
PLIOCENE
(Zanclean/Piacenzian)



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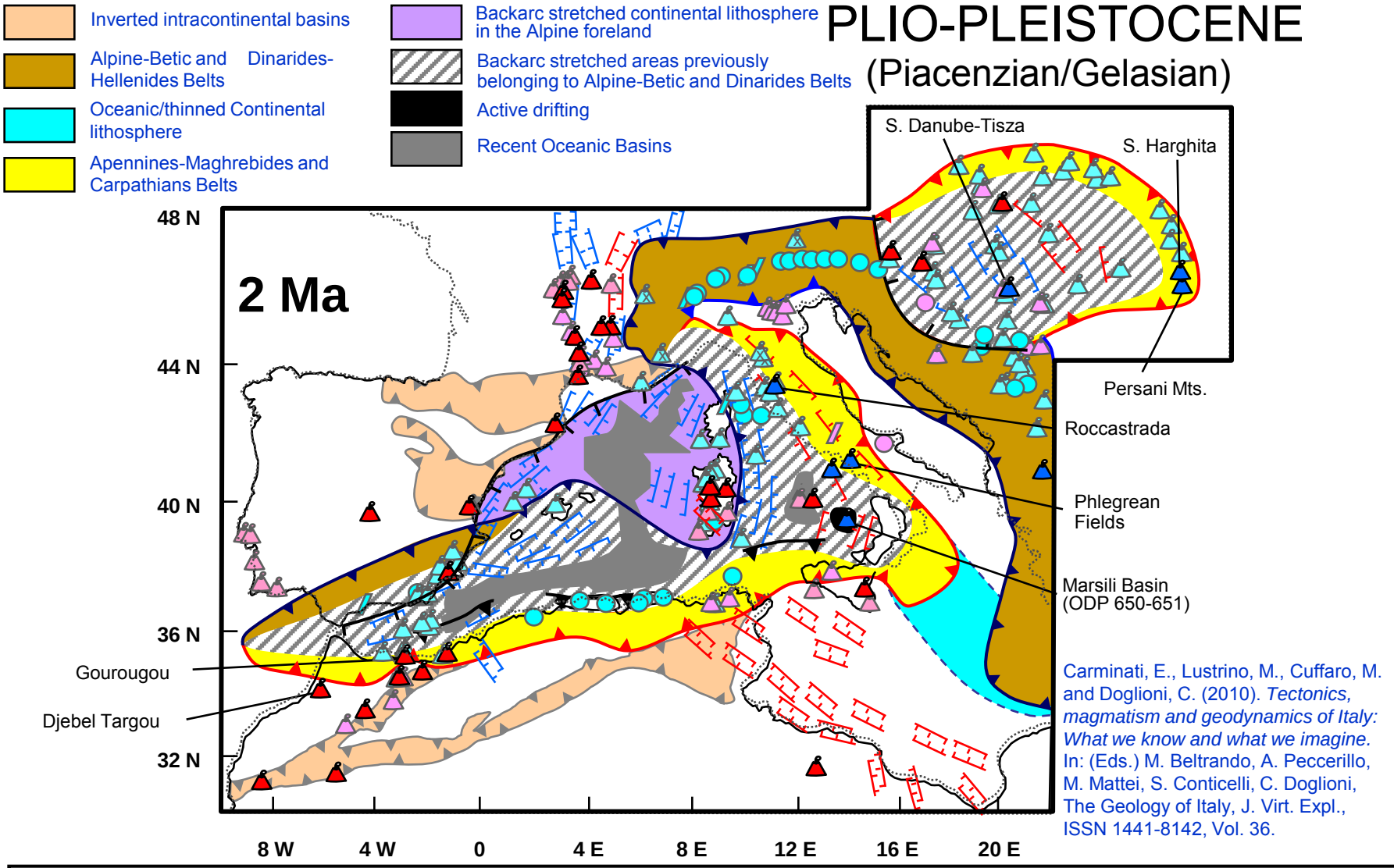
"Anorogenic" magmatism post-dates subduction-related magmatism in the Betics. Slowing of the Apennines-Maghrebides subduction retreat and increase of topography due to chocking, where thick continental lithosphere (e.g., Adria) enters the subduction.

PLIO-PLEISTOCENE
(Piacenzian/Gelasian)



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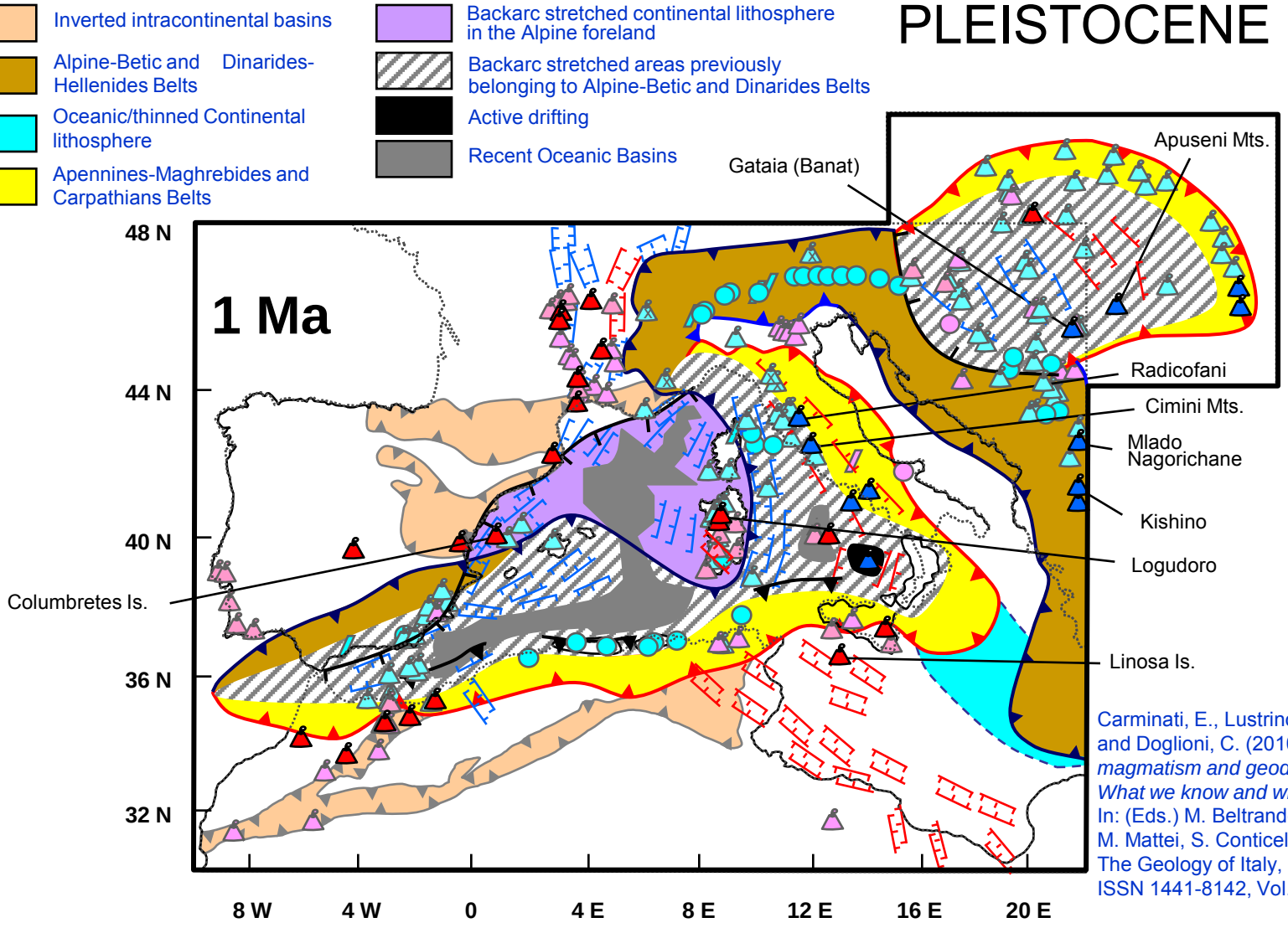
Diachronous (eastward younging) N-directed thrusts start, developing along the Maghrebian Africa and N Sicily.

PLEISTOCENE



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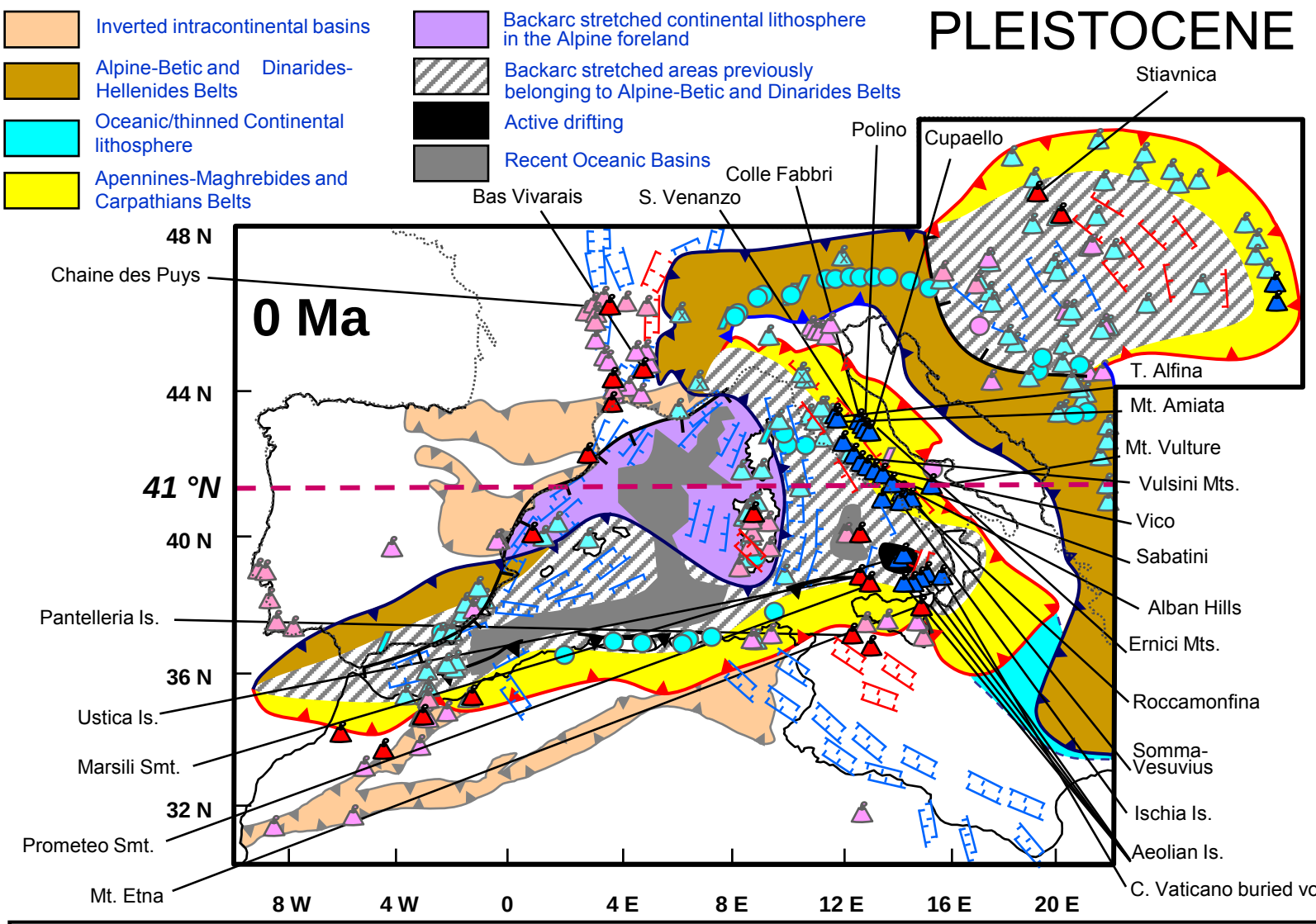
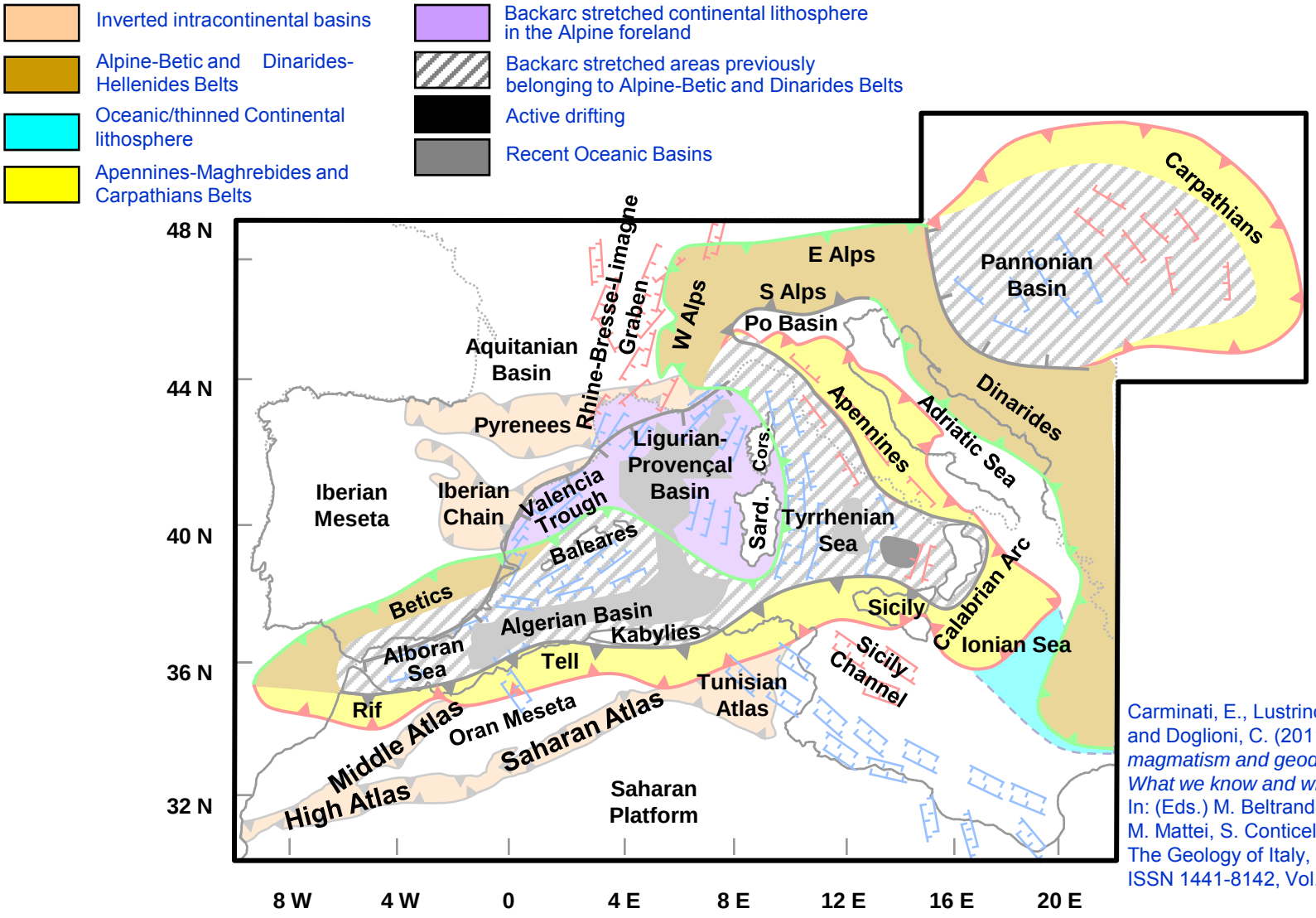


Full development of the Roman Magmatic Province and Aeolian Islands subduction-related igneous activity. Chemical differences between igneous rocks emplaced north of 41° Parallel (mostly potassic and leucite-free lithologies) and south of 41° Parallel (mostly ultrapotassic and leucite-bearing lithologies) along peninsular Italy.



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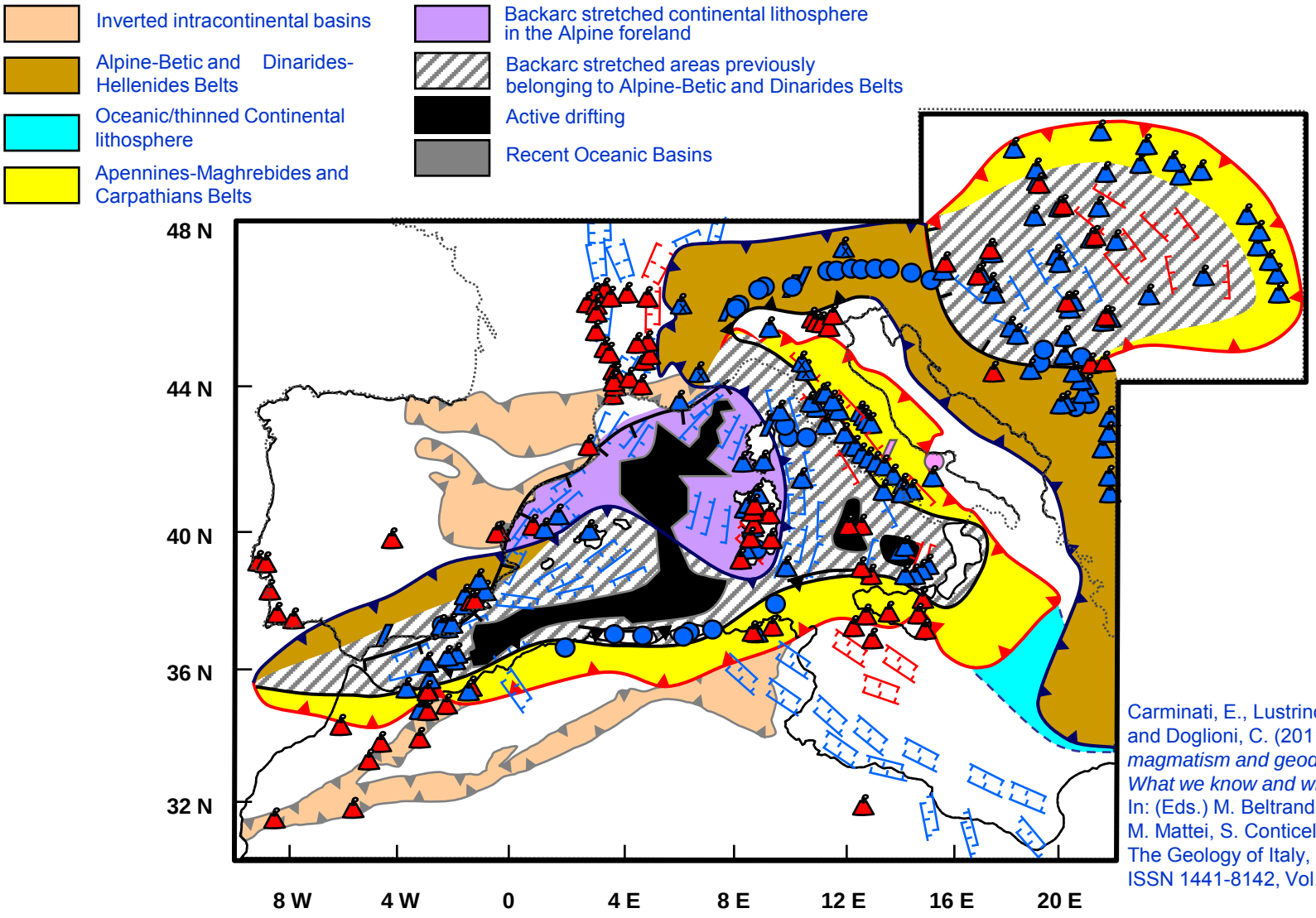

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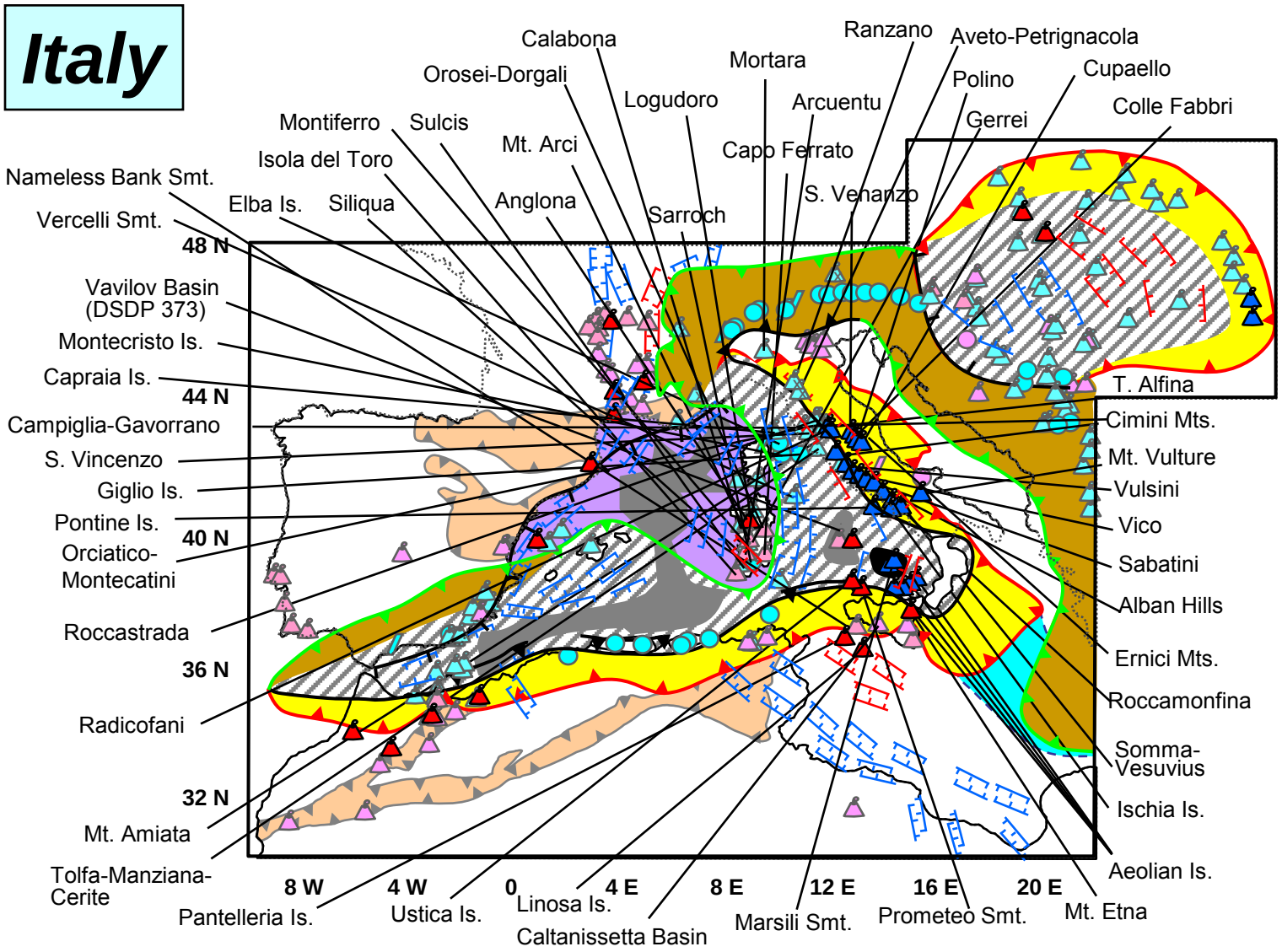
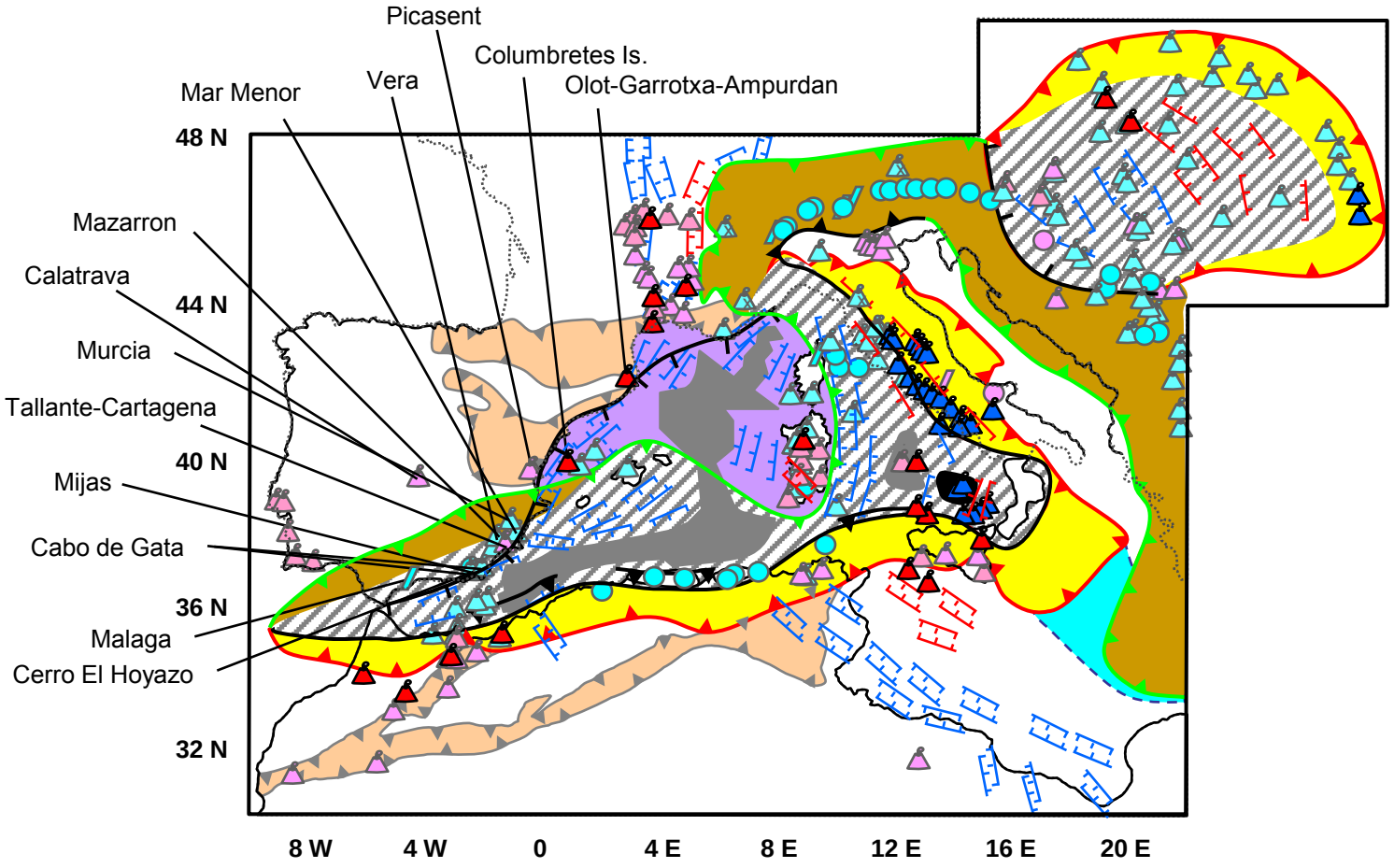
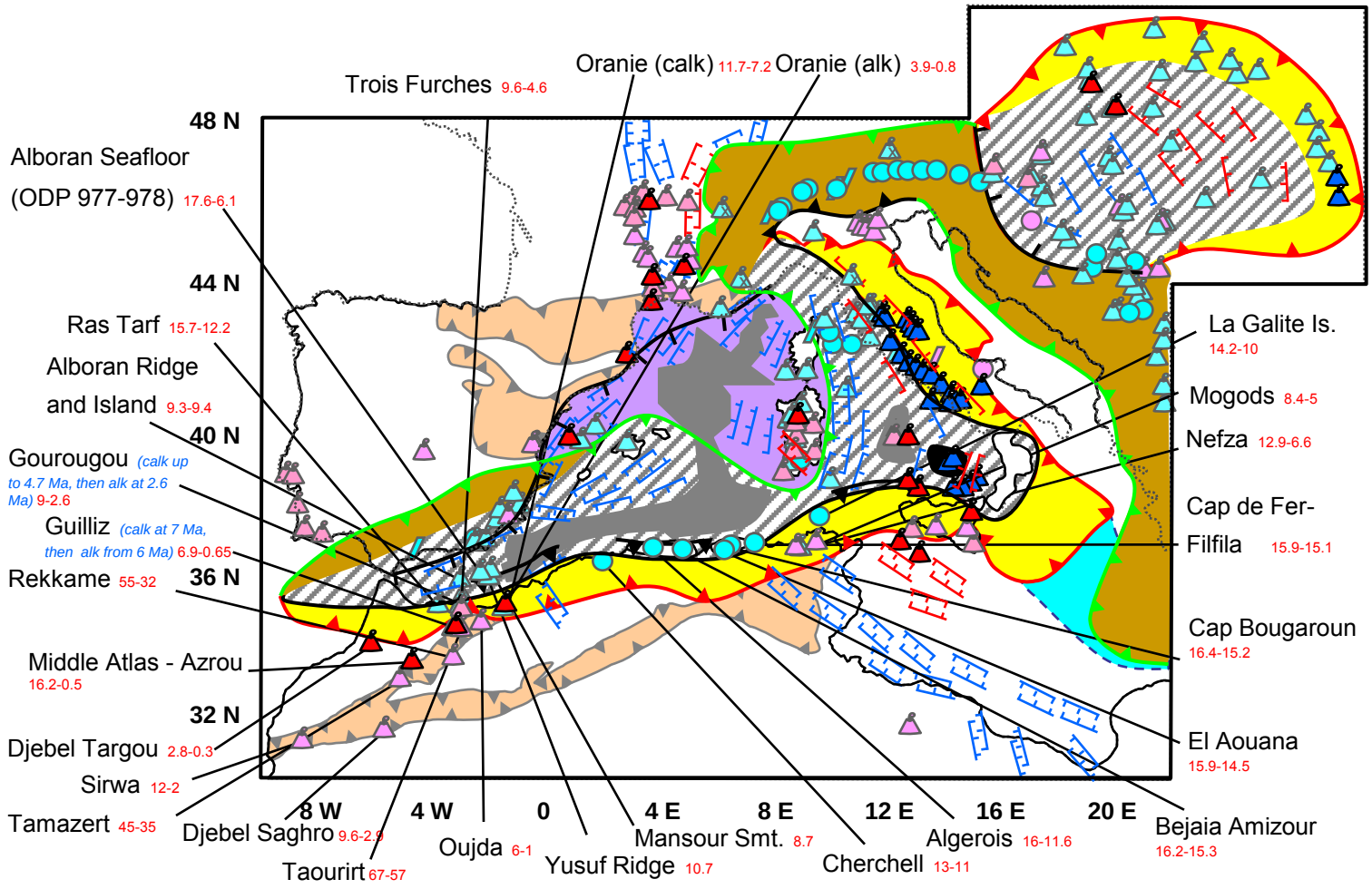
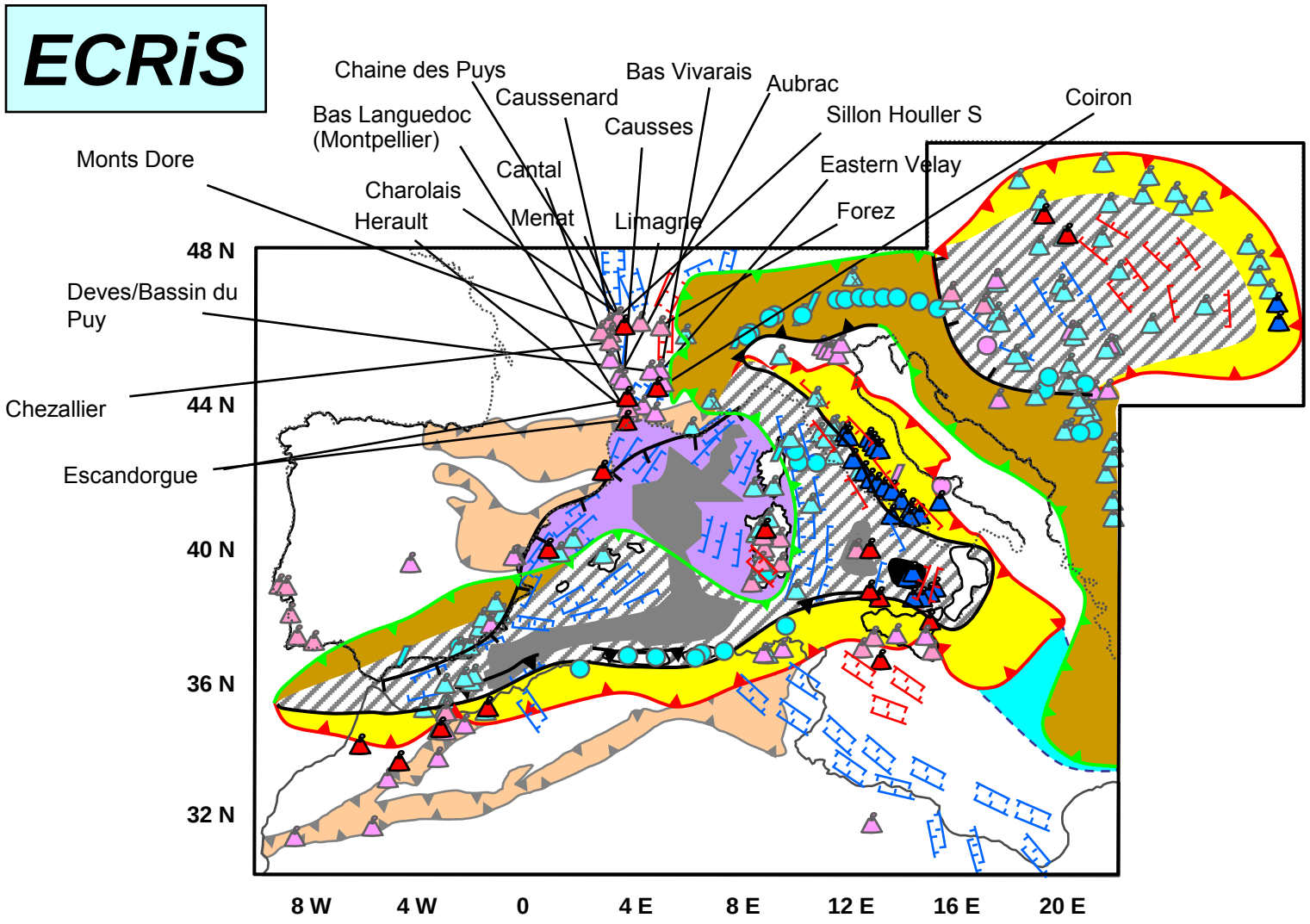

Italy
Calabona
Orosei-Dorgali
Logudoro
Mortara
Ranzano
Aveto-Petrignacola
Polino
Cupaello
Arcuentu
Gerrei
Colle Fabbri
Montiferro
Sulcis
Mt. Arci
Capo Ferrato
Isola del Toro
Nameless Bank Smt.
Elba Is.
Siliqua
Anglona
Sarroch
S. Venanzo
Vercelli Smt.
48 N
Vavilov Basin
(DSDP 373)
Montecristo Is.
Capraia Is.
44 N
Campiglia-Gavorrano
S. Vincenzo
Giglio Is.
Pontine Is.
40 N
Orciatico-
Montecatini
Roccastrada
36 N
Radicofani
32 N
Mt. Amiata
Tolfa-Manziana-
Cerite
T. Alfina
Cimini Mts.
Mt. Vulture
Vulsini
Vico
Sabatini
Alban Hills
Ernici Mts.
Roccamonfina
Somma-
Vesuvius
Ischia Is.
Aeolian Is.
Mt. Etna
8 W
4 W
0
4 E
8 E
12 E
16 E
20 E
Pantelleria Is.
Ustica Is.
Linosa Is.
Caltanissetta Basin
Marsili Smt.
Prometeo Smt.

Spain

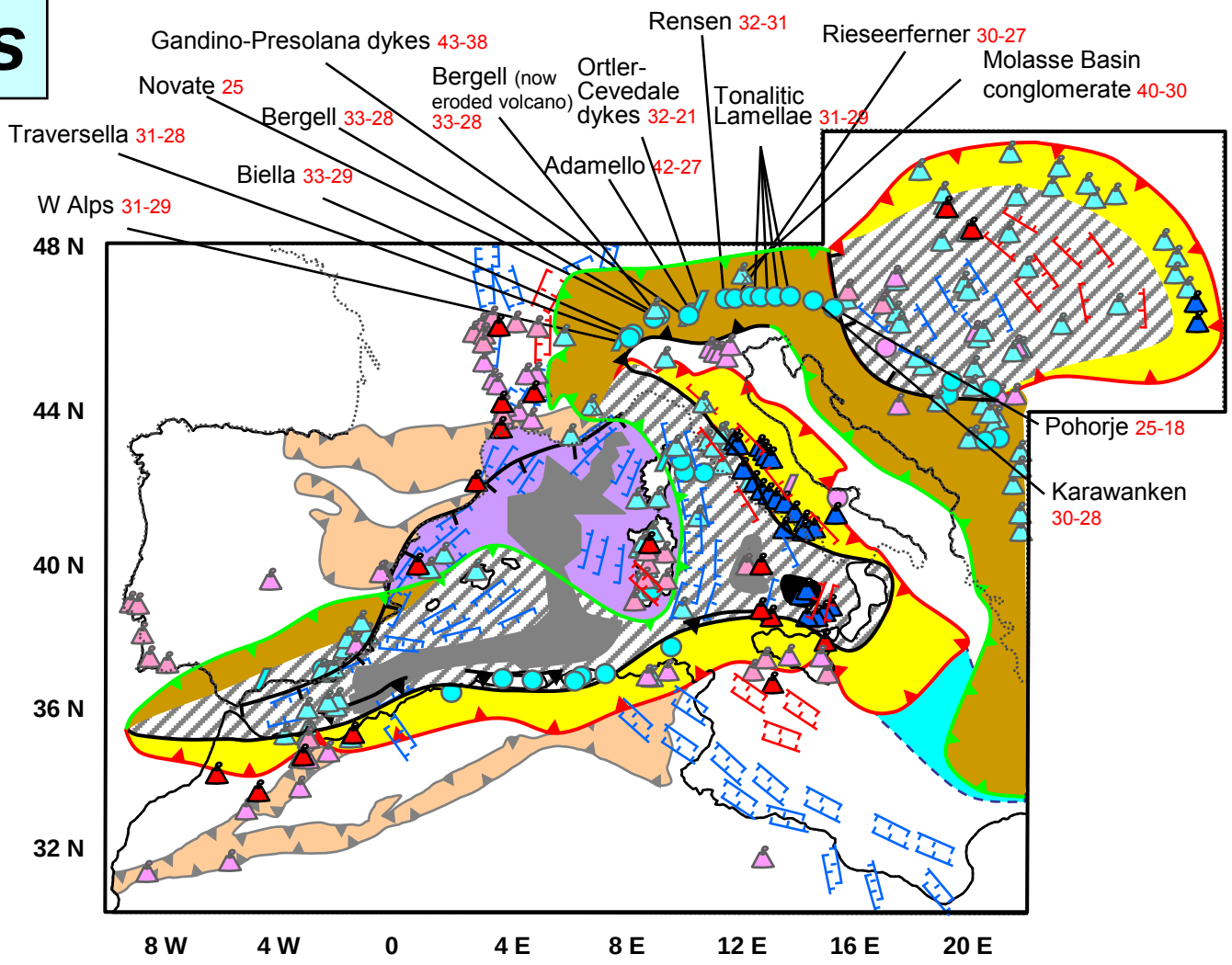

Picasent
Columbretes Is.
Vera
Olot-Garrotxa-Ampurdan
Mar Menor
48 N
Mazarron
Calatrava
44 N
Murcia
Tallante-Cartagena
40 N
Mijas
Cabo de Gata
36 N
Malaga
Cerro El Hoyazo
32 N
8 W
4 W
0
4 E
8 E
12 E
16 E
20 E

Maghreb

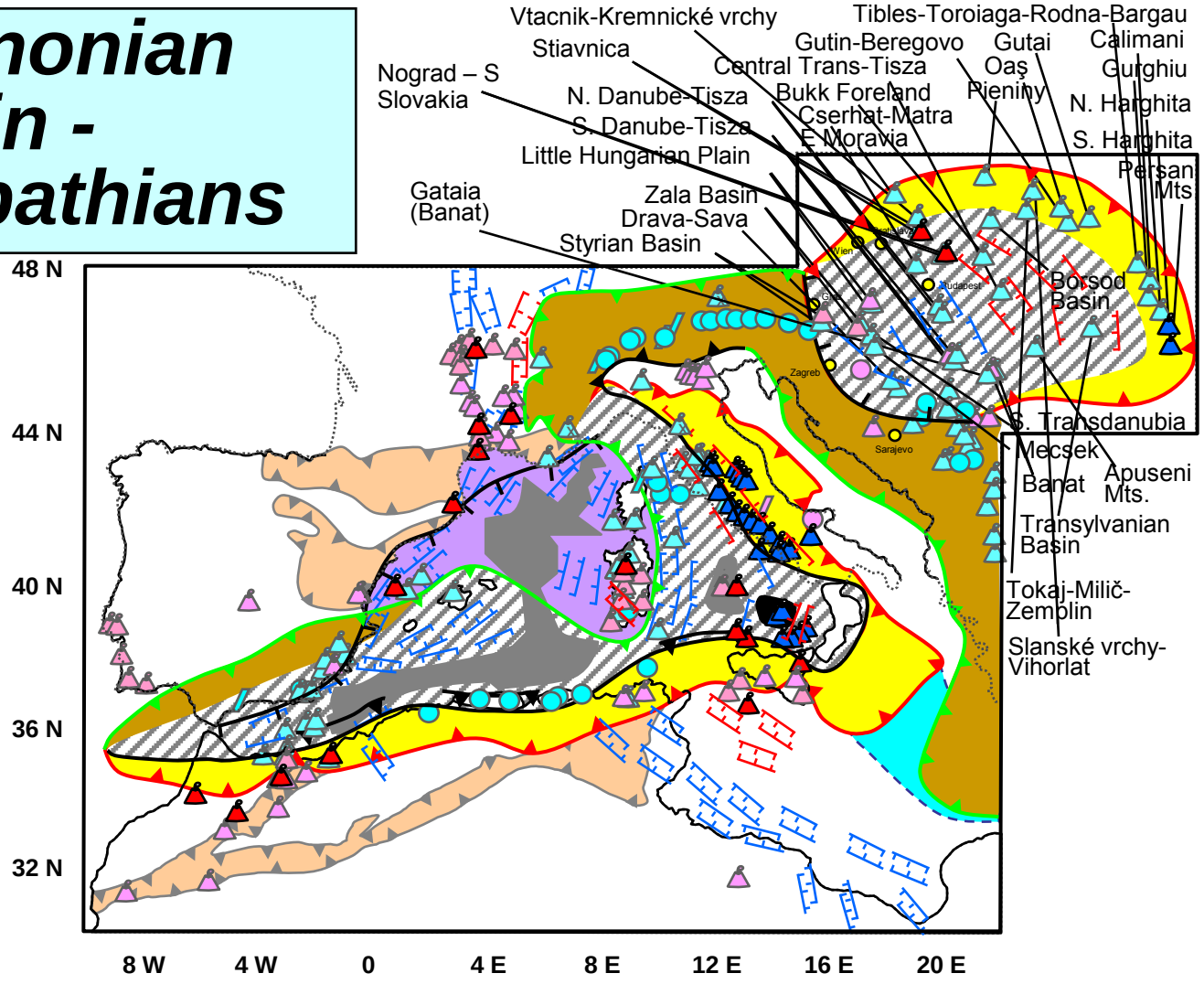

Trois Furches 9.6-4.6
Oranie (calk) 11.7-7.2
Oranie (alk) 3.9-0.8
48 N
Alboran Seafloor
(ODP 977-978) 17.6-6.1
44 N
Ras Tarf 15.7-12.2
Alboran Ridge
and Island 9.3-9.4
40 N
Gourougou (calk up to 4.7 Ma, then alk at 2.6 Ma) 9-2.6
Guilliz (calk at 7 Ma, then alk from 6 Ma) 6.9-0.65
Rekkame 55-32
36 N
Middle Atlas - Azrou
16.2-0.5
32 N
Djebel Targou 2.8-0.3
Sirwa 12-2
Tamazert 45-35
8 W
4 W
0
4 E
8 E
12 E
16 E
20 E
Djebel Saghro 9.6-2.9
Taourirt 67-57
Oujda 6-1
Yusuf Ridge 10.7
Mansour Smt. 8.7
Cherchell 13-11
Algerois 16-11.6
Bejaia Amizour
16.2-15.3
El Aouana
15.9-14.5
Cap Bougaroun
16.4-15.2
Cap de Fer-
Filfila 15.9-15.1
Nefza 12.9-6.6
Mogods 8.4-5
La Galite Is.
14.2-10


ECRiS
Chaine des Puys
Caussenard
Bas Vivarais
Aubrac
Coiron
Bas Languedoc
(Montpellier)
Causses
Sillon Houller S
Monts Dore
Cantal
Eastern Velay
Charolais
Herault
Merat
Limagne
Forez
48 N
Deves/Bassin du
Puy
Chezallier
44 N
Escandorgue
40 N
36 N
32 N
8 W
4 W
0
4 E
8 E
12 E
16 E
20 E

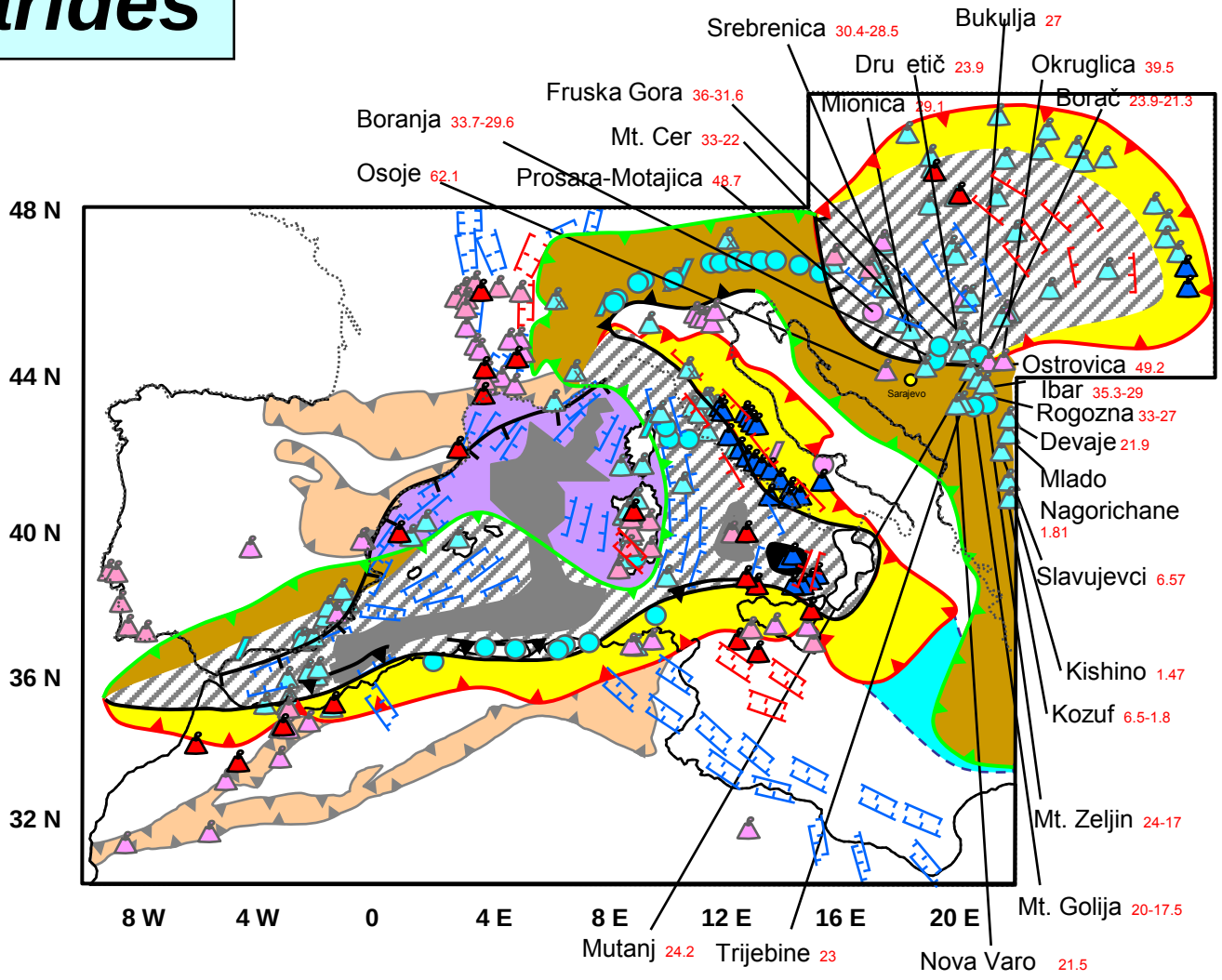
Alps


Gandino-Presolana dykes 43-38
Novate 25
Bergell 33-28
Traversella 31-28
Biella 33-29
W Alps 31-29
Bergell (now eroded volcano) 33-28
Ortler-Cevedale dykes 32-21
Adamello 42-27
Rensen 32-31
Tonalitic Lamellae 31-29
Rieseerferner 30-27
Molasse Basin conglomerate 40-30
Pohorje 25-18
Karawanken 30-28
48 N
44 N
40 N
36 N
32 N
8 W
4 W
0
4 E
8 E
12 E
16 E
20 E

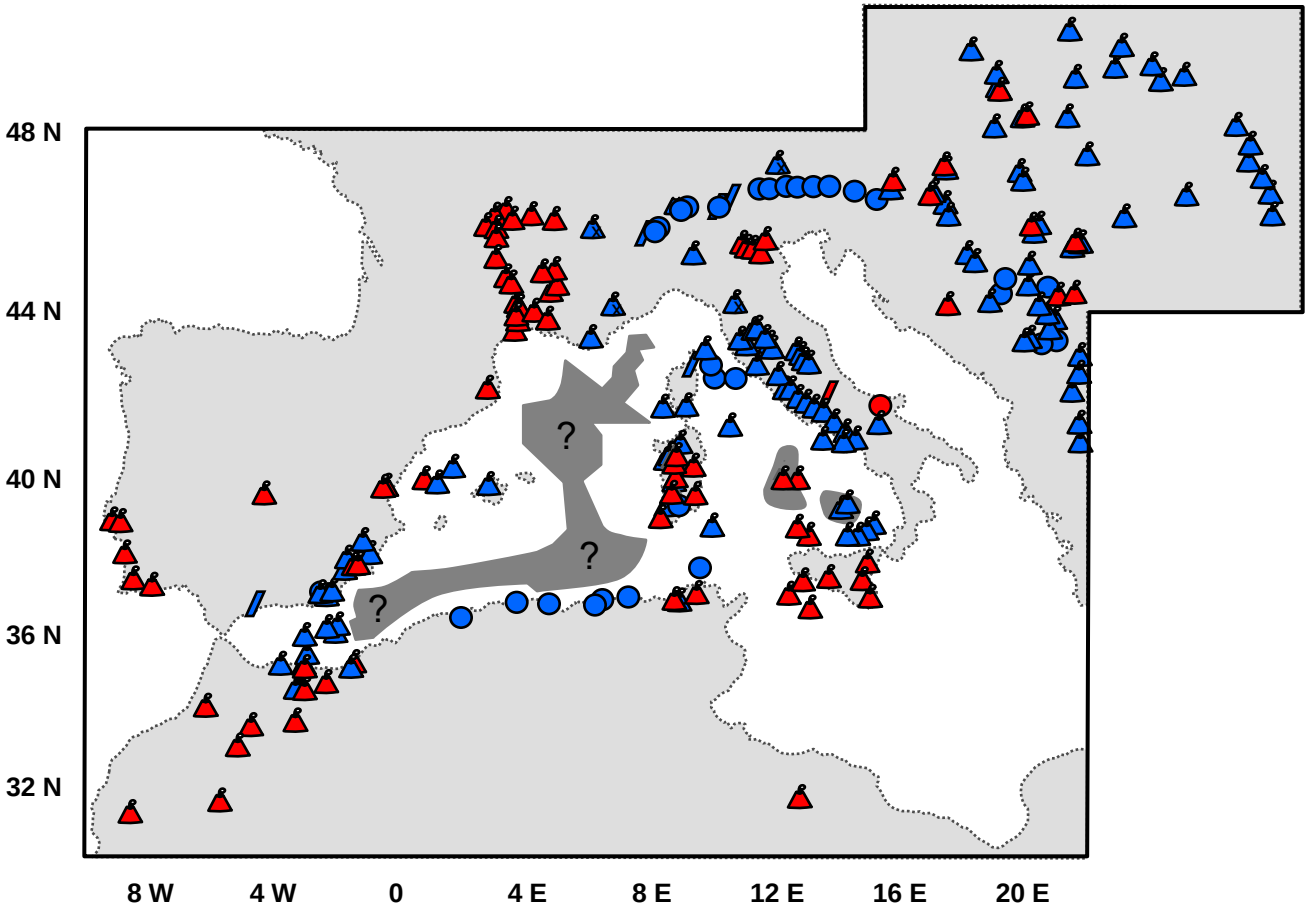
Pannonian Basin - Carpathians



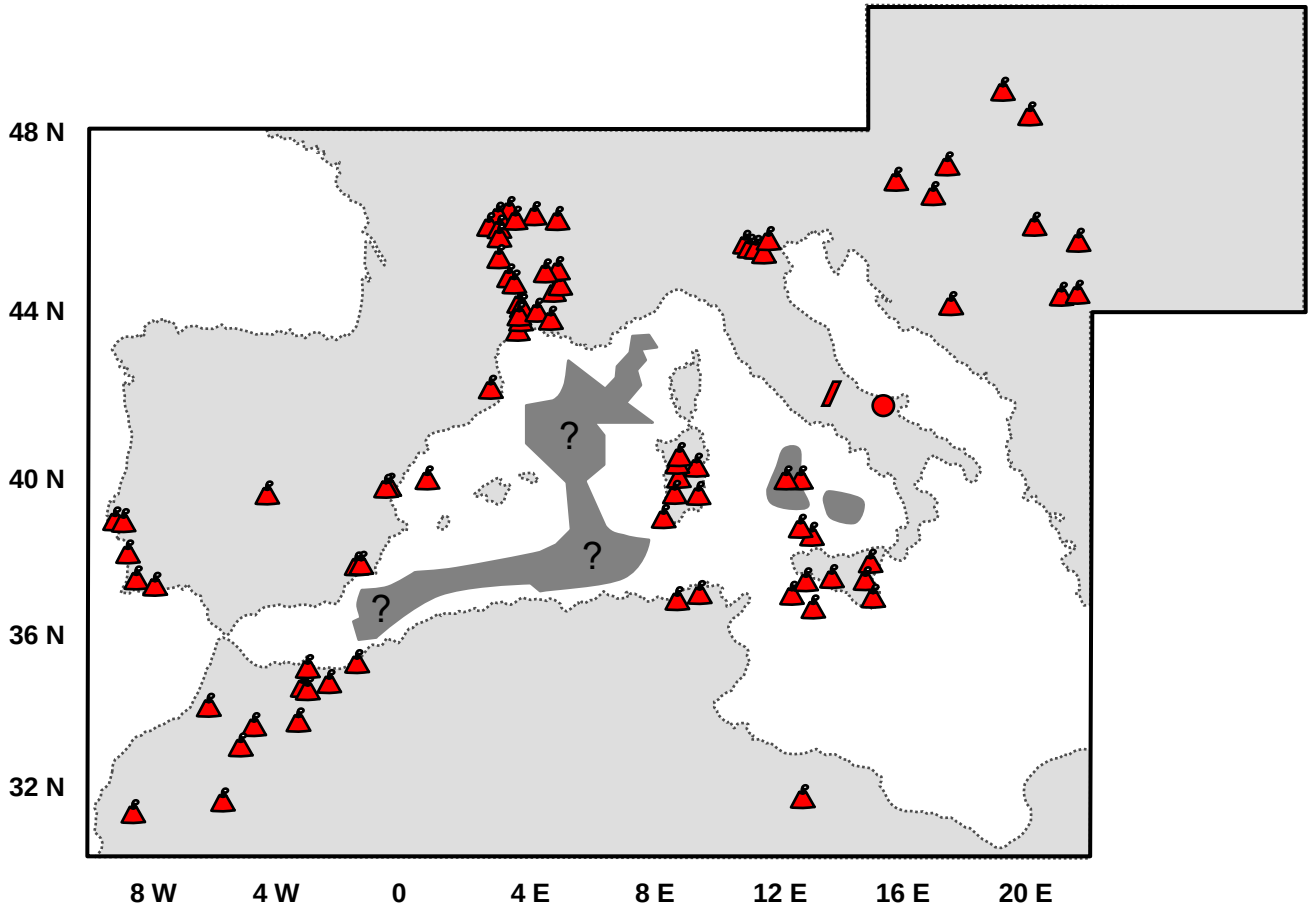
Dinarides


Srebrenica 30.4-28.5
Bukulja 27
Dru etič 23.9
Okruglica 39.5
Fruska Gora 36-31.6
Mlonica 29.1
Borač 23.9-21.3
Boranja 33.7-29.6
Mt. Cer 33-22
Osoje 62.1
Prosara-Motajica 48.7
48 N
44 N
40 N
36 N
32 N
Ostrovica 49.2
Sarajevo
Ibar 35.3-29
Rogozna 33-27
Devaje 21.9
Mlado
Nagorichane 1.81
Slavujevci 6.57
Kishino 1.47
Kozuf 6.5-1.8
Mt. Zeljin 24-17
Mt. Golija 20-17.5
8 W
4 W
0
4 E
8 E
12 E
16 E
20 E
Mutanj 24.2
Trijebine 23
Nova Varo 21.5

Magmatism without tectonic features



Within-plate (anorogenic) igneous rocks



Subduction-related (orogenic) igneous rocks