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The last interglacial transgression in Italy: the breath of the Italian coasts documented by 461 sites

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ABSTRACT

In 2023, the Italian community of Quaternary scientists produced, under the umbrella of METIQ (Modello Evolutivo del Territorio Italiano nel Quaternario (Evolutive Model of the Italian Territory during the Quaternary) coordinated by the Geological Survey of Italy (ISPRA), a Quaternary Map of Italy at 1:500.000 scale that included a database of the last interglacial (LIG) marine highstand's markers along the Italian coasts. The LIG geodatabase lists several well-preserved outcrops and cores, rich in marine fossil features and deposits, straddling the whole Italian coastal areas. This geodatabase relies on three already existing databases, integrated with data from recently published works. In addition, for each site, a re-evaluation of the main chronological and geomorphological data (elevation, age, measurement error, relationship with original sea level and isostatic adjustment correction, GIA) has been made. Coastal areas with the most important LIG inner margins are highlighted. Finally, the long term geological vertical displacement rate is calculated for each site according to the requirements of the METIQ database.

1. Introduction

The existing National Geological Maps of Italy (Guerrieri et al., 2023) represent the Quaternary geological features according to different classification criteria and conceptual models that evolved through time (i.e. lithostratigraphy, chronostratigraphy, biostratigraphy, Unconformity Bounded Stratigraphic Sequence, etc.), different scale of survey, representation and scopes. Moreover, during the last 70 years the great development of Quaternary studies led to an enormous scientific production of regional and local issues, including maps at different scales. For these reasons the Quaternary Map of Italy at 1:500.000 scale (METIQ), will provide a synthetic and harmonised review of the Quaternary record of Italy, spanning from the outcropping rocks and sedimentary successions to the volcanic, tectonic and off-shore features. The Quaternary Map of Italy and the complete METIQ geodatabase have been preliminary presented at the XXI INQUA Congress held in Rome in 2023. This Map aims to provide a synthetic knowledge of Quaternary geology for the assessment of the recent landscape evolution of the

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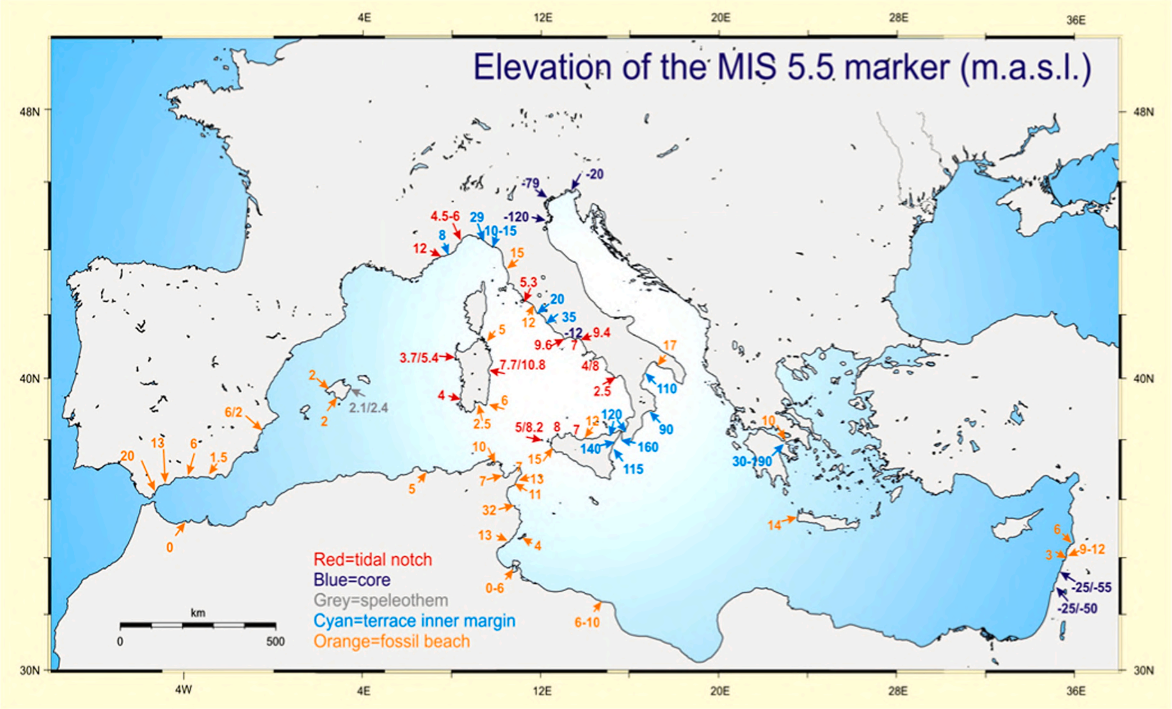

Fig. 1. LIG markers distribution and elevation (m) in the Mediterranean sea (modified from Ferranti et al., 2006).

Italian territory, where the signal of climate changes, palaeoenvironments, tectonics and volcanism can be disentangled at the scale of the whole country according to different proxies. Among these, the traces of the transgression occurred during the Last Interglacial (LIG) along the Italian coastlines, according to the existing knowledge, is also represented. Here we present a new database and a map with 461 points. Unlike previous works, all the elevations to calculate uplift rate have been corrected by isostasy (GIA) and considered the dating of the last transgression 118 ka BP (Antonioli et al., 2018). The geodatabase is based on four existing datasets (Ferranti et al., 2006; Lambeck et al., 2011; Cerrone et al., 2021a; Rovere et al., 2023) whose data were integrated with recently published sites (Bini et al., 2020, Isola et al., 2024 for Campania; Furlani et al., 2017, 2024 for Ustica and Lampedusa; Ferranti et al., 2021, De Santis et al., 2024 for Puglia, Agate et al., 2025; Meschis et al., 2024 for SW, NW and NE Sicily respectively, and in few cases recalibrated for some of their attributes (mostly elevation).

1.1. LIG highstand

The chronological framework of the LIG highstand is mainly constrained by radiometric datings, mostly U/Th of coral, that provide age constraints between about 132 and 116 ka (e.g.; Dutton and Lambeck, 2012; Hibbert et al., 2016; Polyak et al., 2018). The study of the LIG shorelines dates to at least a century ago (Gignoux, 1913), and from that time sea-level indicators left by LIG highstand have been reported from over one thousand sites worldwide (Pedoja et al., 2011; Rovere et al., 2023). The elevation of the LIG highstand above the present-day sea level, measured in stable areas, has been estimated based on coral reefs using various methods (Chappell, 1980; Bard et al., 1990; Blanchon et al., 2009; Thompson et al., 2011; Chauveau et al., 2024). However, these estimates show a significant uncertainty of some meters (Muhs and Simmons, 2017) because corals do not accurately mark the present sea level, since they live across the whole photic zone. Furthermore, in many regions of the world, due to the lack of coral reefs this constrain cannot be used to constrain the elevation of the LIG sea level. In the Mediterranean region, chronological attribution relied on various dating methods, including Optically Stimulated Luminescence (OSL), Electron Spin Resonance (ESR), Amino Acid Racemization (AAR) and U/Th dating, the latter primarily applied to the widely present coral *Cladocora caespitosa* (Linneo, 1767). Additionally, geomorphological markers such as tidal notch speleothems and lagoonal, which offer higher altimetric precision, were considered, although their occurrence is limited (Ferranti et al., 2006; Antonioli et al., 2020; Cerrone et al., 2021a; Rovere et al., 2023 and reference)

1.2. LIG highstand in the mediterranean

Due to the extraordinary geodynamical diversity of the Mediterranean Sea, tectonics plays a major role in the control of the distribution and elevation of the LIG highstand sea-level indicators (Ferranti et al., 2006, 2010). In this Region, a large number of sites preserve markers of LIG such as marine terraces, beach deposits, fossil tidal notches, speleothem concretions and fossils in boreholes. In the western and central Mediterranean area, in Spain (Hearty, 1986; Zazo et al., 1999; Vesica, 2002; Rodriguez-Vidal et al., 2010), Morocco (Gigout, 1960) and Algeria (Stearns and Thurber, 1967; Hearty, 1986), further east in Tunisia (Paskoff and Sanlaville, 1983; Hearty, 1986; Jedoui et al., 2003; Bouaziz et al., 2003) and Libya (Hey, 1956), the LIG is represented by marine terraces and raised beaches, which, commonly lay close to the predicted eustatic elevation. In contrast, in the eastern Mediterranean the LIG markers are often tectonically displaced, but their occurrence is less frequent and they are known from a limited number of sites (Greece: Keraudren and Sorel, 1987; Armijio et al., 1996; Pirazzoli et al., 1996; Westaway, 2002; De Martini et al., 2004; Crete: Hearty, 1986; Lebanon: Fleish, 1956; Stearns and Thurber, 1965; Fleish et al., 1981; Israel: Sivan et al., 1999, 2004; Porat et al., 2003) (Fig. 1).

More recent papers have been published for Israel (Sivan et al., 2016), Cyprus (Zomeni, 2012), Balearic island (Polyak et al., 2018), Creta (Tiberti et al., 2014) and Greece (Karimbalis et al., 2022). Additionally, several important review papers and databases have been published, such as Benjamin et al. (2017), Cerrone et al. (2021a) for Spain, France, Italy, Morocco, Tunisia, and Algeria, Mauz et al. 2020 for eastern Mediterranean and Rovere et al. (2023), which covers global data (World Atlas of Last Interglacial Shorelines-WALIS-), including the

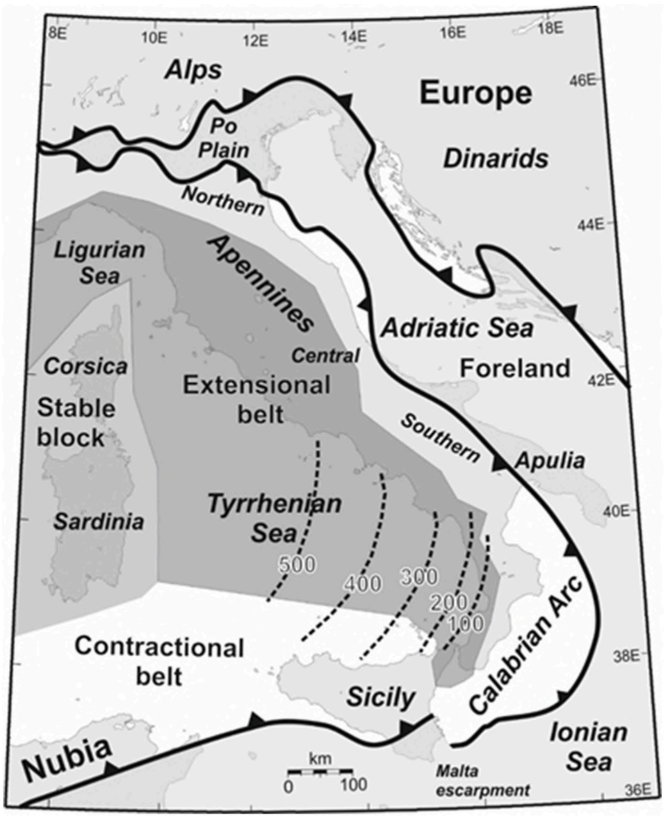

Fig. 2. Adriatic foreland, contractional and extensional belts, and stable blocks, indicated by light grey, white, dark grey and medium grey, respectively. Dashed lines in the southern Tyrrhenian Sea indicate the depth (in km) of the Benioff zone of the Ionian slab (modified after Ferranti et al., 2006).

Mediterranean Sea.

The Mediterranean Sea is characterized by a microtidal setting and the base of a fossil tidal notches (FTN) is considered the most precise marker of the paleo sea level, because its width is closely linked to the local tidal range (Antonioli et al., 2015). Being an erosional feature, the age of FTNs are usually constrained through correlation with adjacent marine deposits containing materials reliable for radiometric datings or biological proxies. FTN can be therefore used to assess and correct the estimate of the relative sea level during LIG.

In general the elevation of all the sea level markers significantly changes mostly due to tectonic or isostatic vertical land movements (VLM) but also volcanic deformation or sediment compaction can be an important factor.

Moreover, ice-driven sea-level changes stem from the contribution of ocean mass variation in response to changes of the continental ice mass. When water mass is transferred from ice sheets to oceans and vice versa, solid earth deforms to restore the isostatic equilibrium under a different surface loading setting. Solid earth deformations and ice masses behave as density anomalies, thus affecting the vertical position of the mean sea surface, which is an equipotential surface of gravity (geoid). This process, known as glacial and hydro-isostatic adjustment (GIA), is responsible for regional relative sea level changes that are modulated in time with the viscous flow of mantle material (Lambeck et al., 2011; Spada and Melini, 2022). In Italy and Spain the LIG trasgression is traditionally also known as "Tirreniano", whose markers (marine terraces, fossil assemblages and corals) were firstly recognised at Cala Mosca in Sardinia by Issel (1914). After that study, several researchers have identified and dated hundreds of sites with evidence of LIG throughout the Mediterranean including Italy (Blanc, 1935, 1936; Hearty, 1986, 1987; Cosentino and Gliozzi, 1988; Bordoni and Valensise, 1998; Zazo et al., 1999, 2003, 2013; Nisi et al., 2003; Ferranti et al., 2006, 2010; Amorosi et al., 2014; Antonioli et al., 2018).

1.3. The Quaternary relative sea-level changes along the Italian coast

The evolution of the Italian coasts during the Quaternary is strictly related to the geodynamic characteristics of this region, which are driven by lithospheric processes showing different structural and kinematic interaction, including subduction, fold-and-thrust belt development, back-arc spreading and extension (Fig. 2).

The Adriatic Sea and surrounding promontories represent the remaining part of the Adriatic continental lithospheric block caught between the Europe and Africa plates and serving as the foreland domain of the Southern Alps, Dinarids and Apenninic thrust belts (Fig. 2) (Royden et al., 1987; Carminati et al., 2010). Similarly, the Ionian Sea straddles the transition between the front of the Hellenids and Apennines along the Adriatic Sea, and the Hyblean foreland with the front of the Sicilian-Maghrebian chain in Eastern Sicily. Most of the Ionian Sea is thought to be floored by oceanic lithosphere subducting to the west below the Calabrian Arc (Akimbekova et al., 2023).

The Tyrrhenian Sea represents a back-arc basin opened and migrated eastward behind the Apennines in the wake of the retreating Adriatic–Ionian slab (Malinverno and Ryan, 1986). Today, seismic tomography and deep earthquakes beneath the south-eastern Tyrrhenian Sea identify the subducted Ionian slab (Fig. 2) (Selvaggi and Chiarabba, 1995; Chiarabba et al., 2008). During Quaternary, the eastern and southeastern margins of the Tyrrhenian basin experienced extension, which was locally accompanied by volcanism. Displacement along normal faults articulated the Tyrrhenian coast of Italy and Sicily in a complex alternation of subsiding basins and uplifting rocky promontories (Ferranti et al., 2006).

Calabria and north-eastern Sicily form the Calabrian Arc, a forearc terrane emplaced above the NW dipping-Ionian slab (Fig. 2). During the Quaternary and throughout the present, the entire region experienced vigorous uplift (Westaway, 1993; Miyauchi et al., 1994) accompanied by extensional faulting along the Tyrrhenian Sea margin and the chain axis (Ghisetti, 1992; Monaco and Tortorici, 2000). Uplift and related extension are interpreted as a response to slab detachment and consequent asthenospheric flow (e.g., Wortel and Spakman, 2000; Faccenna et al., 2011), or as being supported by asthenosphere wedging beneath the decoupled crust (Gvirtzman and Nur, 2001).

The islands of Sardinia and Corsica are detached fragments of the Alpine foreland and orogenic belt (Patacca and Scandone, 2007). The western and eastern side of this block have been affected by extensional tectonics related to the rifting of the Ligurian–Balearic Sea (Oligocene–Miocene) and Tyrrhenian Sea (Miocene–Pliocene), respectively (Fig. 2), and were tectonically stable during the Quaternary (Ferranti et al., 2006).

As a result of these complex tectonic processes, the Italian coasts are characterised by alternating tectonically stable and unstable sectors, where the LIG markers have been displaced, raised or lowered, respect to the predicted eustatic position. Therefore, the elevation variability of the LIG markers is attributed mainly to regional or local tectonic processes and/or sedimentary compaction (Miyauchi et al., 1994; Ferranti et al., 2006, 2010; Andreucci et al., 2006, 2009,; Antonioli et al., 2011; Cerrone et al., 2021b; Sechi et al., 2023).

Ferranti et al. (2006) provided a review of the LIG coastline position in Italy with the aim of assessing the vertical component of the tectonic displacements along the coast in the last 130 ky. These authors observed a significant alongshore elevation differences fo the LIG markers between +175 and −125 m respect to the present-day sea level and attributed these differences to the combination of regional and local tectonic, volcanic or diagenetic processes. Most of the Sardinia and northern Tyrrhenian Sea coasts do not show significant tectonic activity, central Tyrrhenian Sea coasts are characterised by stable promontories and subsiding coastal plains, and only in few sectors weak uplift is assessed. The subsidence of the coastal plains would be related to

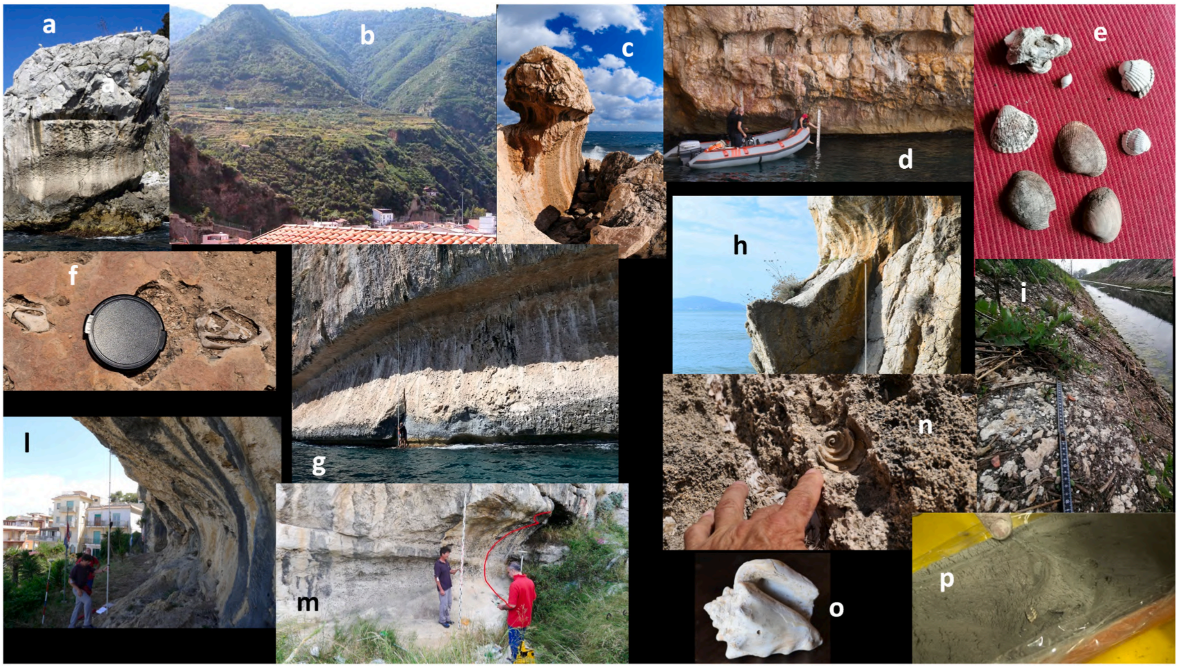

Fig. 3. Examples of the LIG highstand indicators. a: tidal notch at Capri (central Italy); b: an uplifted marine terrace, inner margin at 127 m at Scilla (Calabria); c: tidal notch in Sardinia, Orosei gulf (central Italy) at 10.7 m; d; tidal notch at Buggerru (Sardinia) at 3.7 m; e: lagoonal fauna from outcrops in Pontina plain (central Italy) at −2 m; f: two *Thetystrombus latus* (Gmelin, 1791) cropping out at Favignana island (south Italy) at 4.6 m; g: tidal notch at Orosei (Sardinia) at 9.3 m; h: fossil tidal notch at Talamone (central Italy) at 4.8 m; l: a fossil tidal notch at Minturno (central Italy) at 12.5 m; m: a tidal notch at Terracina (central Italy) at 8.0 m; n: a *Thetystrombus latus* in a sandstone outcropping in Favignana island (south Italy) at 4.3 m; o: a *Th. latus* from Puglia, Taranto; p: a fragment of *Cerastoderma* s.p. lagoonal shell, from a core in the Veneto plain (NE Italy) at −42 m (see also Fig. 4).

extensional faulting locally enhanced by volcano-tectonic collapse whereas uplift is mainly the result of magmatic unrest. The strong uplift recorded in southern Calabria and northeast Sicily is the response to deep crustal delamination beneath the Calabria forearc terrane. The above mentioned regions that are rapidly uplifting correspond to the sectors of higher seismic release and surface horizontal motion documented by geodetic velocities, underlining the four-dimensional nature of deformation.

The central Adriatic Sea is affected by weak thrust-related uplift, whereas foreland flexure in northern Adriatic led to a locally intense regional subsidence. The rapidly uplifting regions correspond to the sectors of higher seismic release (https://diss.ingv.it/) and surface horizontal motion documented by geodetic velocities (Devoti et al., 2017), underlining the four-dimensional nature of deformation.

2. Material and methods

The LIG geodatabase discussed here, lists 461 well-preserved and published sites with geomorphological and sedimentary sea-level indicators straddling the whole Italian coasts (Fig. 3). Although, Pasquetti et al. (2021) performed a review of the reliability in terms of geochronology on a limited data set of LIG sites, for the purposes of this work the database discussed in this article takes into consideration the total number of the known and available LIG sites. Furthermore in order to calculate the displacement rate, following Ferranti et al. (2006) LIG database, we do not take into account the single datings but the fact that they fall within the MIS 5.5 to which we attribute an age of 118 Ka, as calculated for Mediterranean sea by Stocchi et al., 2018; Antonioli et al., 2018.

The geodatabase relies on three existing databases (Ferranti et al., 2006; Lambeck et al., 2011; Cerrone et al., 2021a, Rovere et al., 2023) updated with the most recently published sites. Each LIG site included in this review and not publihed by any of us (the Authors) underwent a critical check in terms of the assessment of the elevation and chronology. Finally, isostatic adjustment correction and the average uplift or downlift rate was calculated as a final and novel output for all the sites. As regards the LIG elevation, the check and re-evaluation was performed only for the sites published between the 30s of the XX century (Table S1, ie the “fathers” of Quaternary geology who worked in Italy as Segre, Blanc, Malatesta, Dumas, Brancaccio, Dai Pra, Hearty, etc.) and the earliest XXI century, before the release of Google Earth, on 2005. The revision of the elevation has been mostly carried out by the use of Google Earth, much more reliable than the original values reported in literature often assessed on the basis of topographic maps with contour equidistances of 10–25 m. Concerning the core records, the elevation data were recalibrated choosing the lowest values of elevation of the LIG deposit. Finally there were then many cases where we used the coordinates of the sites where it was sampled and dated at a slightly lower elevation but it was then reported at a slightly higher elevation until the inner margin of the correspondent marine terrace.

All the elevation data are assessed using the modern sea level, or sea-level datum as reference. For most of the more recently published data the elevation uncertainties used to evaluate elevation of sea level markers, were already reported due to the use of GPS, barometric altimeter, auto or hand level, metric tape etc. In the cases where the elevation measurement technique or the sea-level datum was not reported in literature, we estimated the elevation with respect to the mean sea level assuming that measurements were collected with hand level or metric tape, following Rovere et al. (2016). No data reported elevation with respect to mean low water spring, high or low-level tide. Measurements taken from Google Earth uses digital elevation model (DEM) data collected by NASA’s Shuttle Radar Topography Mission (SRTM) enabling 3D view of the whoel earth. The elevation data provided by the Shuttle Radar Topography Mission (SRTM) is referenced to the WGS84 (World Geodetic System 1984) datum, converted from the orthometric version using the EGM96 geoid. SRTM data represents orthometric heights, which are essentially the heights above the Earth’s mean sea level, referenced to the WGS84 ellipsoid. The planimetric resolution is

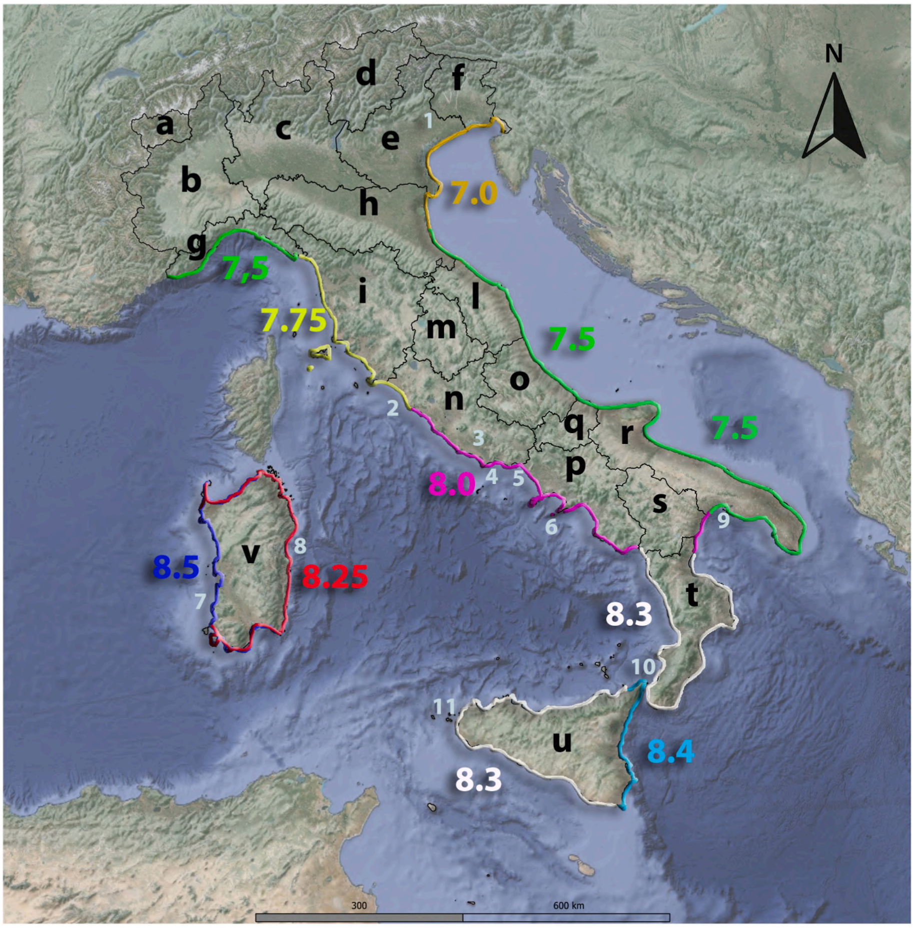

Fig. 4. GIA correction values (m) used for LiG uplift rates calculation. The numbers indicated the maximum higstand corrected with GIA. The letters indicate the 20 Italian Regions. In particular, clockwise: g Liguria, I Tuscany, n Lazio, v Sardinia, p Campania, t Calabria, u Sicily, s Basilicata, r Puglia, q Molise, o Abruzzo, L Marche. h Emilia-Romagna, and Veneto, f Friuli Venezia Giulia. The white numbers indicate some localities quoted in Fig. 2 caption: 1) Veneto Plain, 2) Talamone, 3) Pontina Plain, 4) Terracina, 5) Minturno, 6) Capri, 7) Buggerru, 8) Orosei gulf, 9) Taranto, 10) Scilla, 11) Favignana island.

20 m, while the relative precision in elevation is ±6 m (90 % confidence interval).

All published LIG sites in Italy have been considered in the text or references. However, for a subset of these sites (13 sites, see Table S1), we did not use them to calculate displacement rates due to uncertainties caused by the sedimentation environment and because they did not represent the most indicative elevation to calculate vertical movement. In these cases, we wrote in Table S1 “Not determined”, and we indicated them (Table S1) with a square in Fig. S2.

Therefore, the literature data of our review is limited to the 2024 with one exception for 2025. For the assessment of the vertical displacement rate, the assessment of the Glacial and hydro Isostatic Adjustment (GIA) and the chronology of the maximum highstand (based on the correlation with the LIG highstand duration) for the Mediterranean was taken into consideration as reported by Stocchi et al. (2018) and Antonioli et al. (2018) using the Selen geophysical model Following this model, the maximum highstand of the LIG is assumed to occur at 118 ka BP.

The other models (Ice G5 and Ice G6, which show the higstand at 124 ka, Peltier et al., 2015) infact never exceed for the LIG higstand 4 or 1.5 m of altitude respectively, whereas along the Italian coasts LIG FTNs are found at about 8 m, i.e. E-Sardinia, S-Lazio and NW-Sicily that are considered tectonically stables where the Selen geophysical model (which reaches and exceeds 8 m with an highstand of 118 ka) was defined. The glacial and hydro-isostatic adjustment (GIA) drove relative sea level RSL changes within the central Mediterranean basin with regional variation that are and significantly distinct from the eustatic signal. Overall, the variability of the maximum GIA elevation is between 1 and 2.5 m Therefore, for GIA correction values, the following LIG highstand data have been considered as calculated from Antonioli et al., 2018: 8.5 m for Western Sardinia, 8.25 m for Eastern Sardinia, 8 m for central Tyrrhenian coast, 8.3 m for Calabria m for Sicily (specifically for Eastern Sicily), 7.75 m for the central and northern Tyrrhenian regions, 7.5 m for Liguria, Apulia, and Abruzzo, and 7 m for the northern Adriatic Sea (Fig. 4). These values are referred to the present sea level.

As an example, to calculate in column 7 of Table S2, consider a fossil tidal notch at an elevation (H) of 25 m a.s.l. in western Sardinia, the following formula can be applied: $(H - GIA) \div Age = displacement\ rate$ in our example $(25\,m - 8.5) \div 118\,ka = 0,14\,mm/y$ r.

3. Results: LIG-highstand markers and vertical displacement rates

The geodatabase lists 461 sites with LIG sea-level indicators (Table S1) showing significant differences in elevation from +175 to −125 m a.s.l. due to their history interplay of regional and local tectonic processes, including faulting, compaction, volcanic deformation and partially for GIA. For each site, the elevation is assessed based on markers coupled with a refined age assessment locally supported by radiometric datings (OSL, ESR, U/Th, AAR, or Senegalese fauna, etc.) reported in the literature (Table S2 and file.kmz S3). The best markers are considered FTNs and lagoon sediments preserving significant fossil assemblages The LIG chronological assessment for the Mediterranean sea is also facilitated by the presence of numerous gastropod such as the

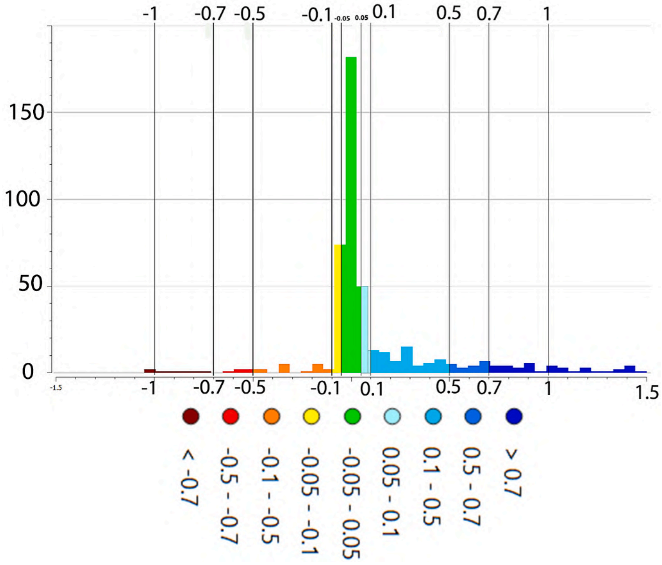

Fig. 5. Statistical analysis of the vertical land movement rates (mm/yr) shown in Fig. 4.

Thetystrombus latus, (Gmelin 1791) belonging to the so-called Senegalese fauna (well known in the past before as *Strombus bubonius* Lamarck, 1822 and then as *Persististrombus latus* (Gmelin, 1791). This is a gastropod that firstly occurred in the Mediterranean during the LIG and then extinct, except for a small area around the Strait of Gibraltar (Mauz and Antonioli, 2009).

By calculating the displacement rate for each site, nine different classes have been determined (>0.7; 0.5/0.7; 0.1/0.5; 0.05/0.1; −0.05/0.05; −0.05/-0.1; −0.1/-0.5; −0.5/-0.7; <-0.7 mm/yr) in order to emphasise the distribution of the uplifting, stable and subsiding Italian coastlines since the LIG (Fig. 5 Figure S2).

Fig. 5, displacement rates (mm/yr) of the new 461 points database: green is stable, red downlifting, blue uplifting, source: database LIG, the Geological Survey of Italy, ISPRA.

As regards the distribuitions of displacement rate around the Italian coast, the results (shown in Table 1) are: (256 sites are tectonically stable; 35 sites with uplift rates higher than 0.7 mm/yr; 28 sites with uplift rates between 0.5 and 0,7 mm/yr; 92 sites with uplift rates between 0.1 and 0.5 mm/yr; 11 sites with subsidence rates between −0.05 and −0.1 mm/year; 15 sites show subsidence rates between −0.5 and 0.1 mm/yr, while 12 sites show subsidence rates between −0.7 and −0.5 mm/yr. Finally 10 sites show vertical rates higher than −0.7 mm/yr. The results indicate that 55 % of the sites are stable, 19 % are in a slight uplift and 13 % are in a slight uplift. While 5.6 % are in a slight downlift and 22 % are in a downlift. (Figs. 5-7).

Table 1
Number and percentage distribution of displacement rate of the 461 different investigated sites.

Uplifting sites (rates mm/yr)			Stables sites	Subsiding sites (rates - mm/yr)			
Δ%> 0,7	0,5> Δ%> 0,7	0,1> Δ%> 0,5	Δ% = 0	0,05> Δ%> 0,1	0,1> Δ%> 0,5	0,5> Δ%> 0,7	Δ%>0,7
35 (7,6 %)	**28 (6,1 %)**	**92 (19,9 %)**	**256 (55,50 %)**	**11 (2,4 %)**	**15 (3,2 %)**	**12 (2,6 %)**	**10 (2,2 %)**

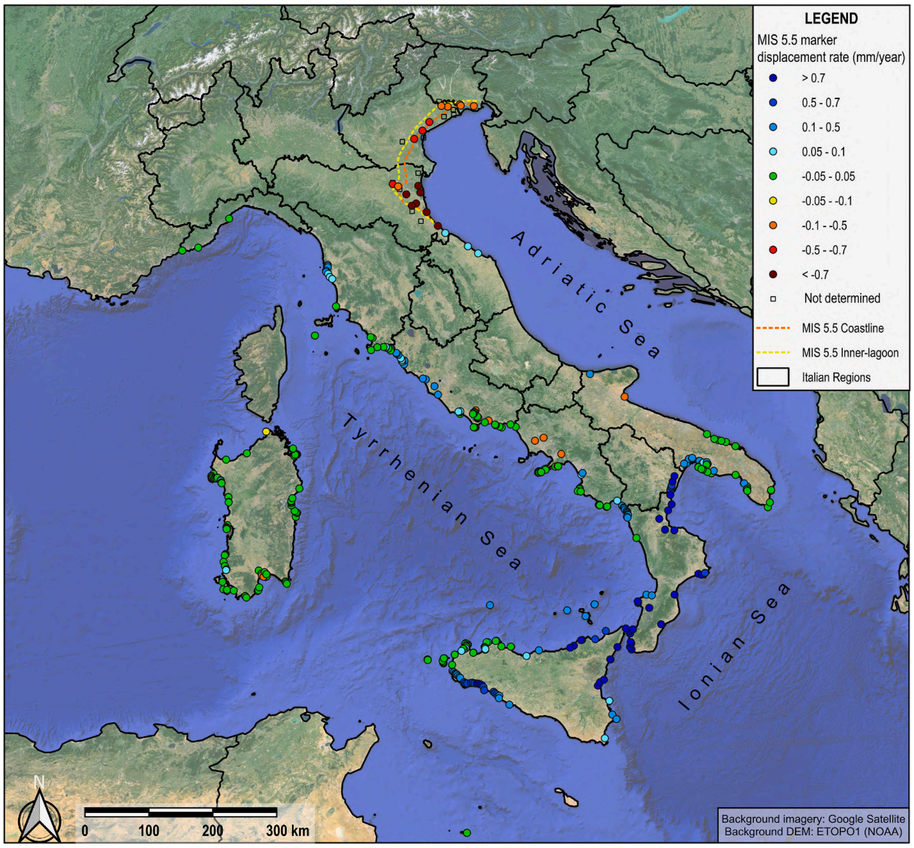

Fig. 6. The 461 sites and displacement rate (mm\yr).

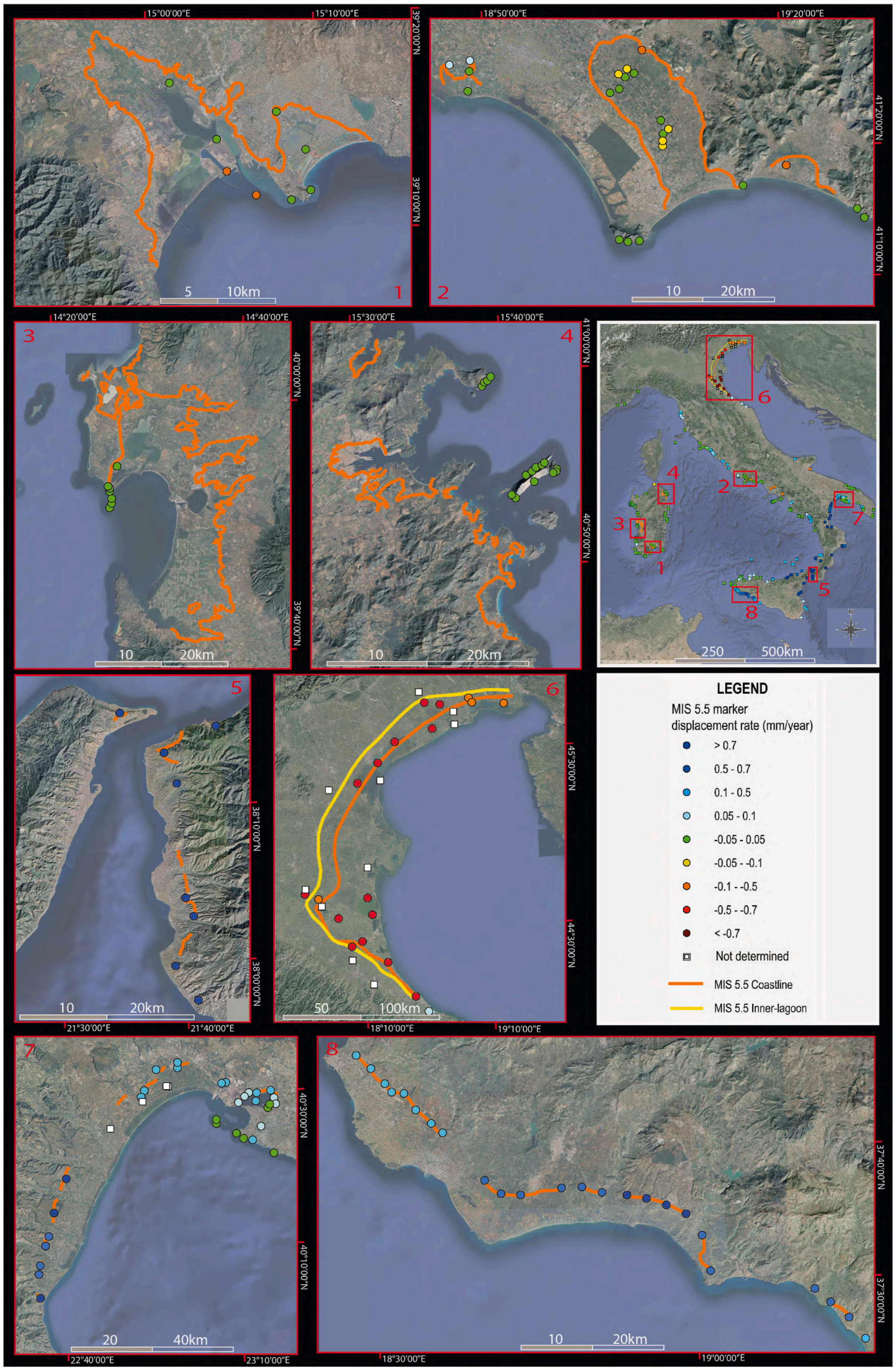

Fig. 7. Some Last Interglacial inner margin on Italian coastline. Stable coastal area: 1 Cagliari Plain, 2 Pontina and Fondi Plain, 3 Oristano Plain, 4 Olbia Plain. Subsiding coastal area: 6 Po Plain (See also Fig. 4). Uplifting coastal area: 5 SW Sicily, 7 Soutern Calabria, 8 Southern Basilicata. The attributes and relative values for the 461 sites studied are reported in Table S2 caption.

4. Discussion

The displacement rates (Table S1, Figs. S2 and S3) calculated using LIG maximum highstand, provide important information for the management of Italian coasts compared with the present-day vertical land movement (The European Ground Motion Service (EGMS) https://egms.land.copernicus.eu/), Cardello et al., 2025. Data can be used for predictive models for the next 75 years along some coastal plains of Italy (Antonioli et al., 2017; Marsico et al., 2017; Deiana et al., 2021; Cappucci et al., 2024). In particular, the knowledge of the downlifting rates is crucial to mitigate the risk for possible future sea-flooding having effects on the numerous human settlements, infrastructures and activities located just a few meters from the shoreface (Bonaldo et al., 2019; Vacchi et al., 2021) that in Italy are characterised by a microtidal regime (between 32 and 46 cm tidal range, National tide gauge network, ISPRA, 2024). As known, relative sea-level change is the sum of eustatic, GIA and tectonic factors also related to local soil compaction and human activities. While eustasy is a global and time-dependent factor, GIA and tectonics changes at regional scale whereas the last two are strictly related to each coastal site (Lambeck et al., 2011). Knowledge of precise displacement rate is notable, especially for peculiar subsiding coastal areas such Venice where it is even greater than the eustatic factor

(Zanchettin et al., 2020). The vertical rates calculated in previous databases are here corrected due the better location of the sea level markers and reassessment of the elevation data, for the correction of GIA and for the assumption of the LIG highstand to 118 ka On the other hand, other research published for the Italian coasts have also found an agreement with a peak for LIG at 118 ka (Giaccio et al., 2023). If we take into consideration some sites with high uplift or downlift vertical rates and we compare them with those of vertical rates of the previous database, we can notice, for examples, that in Comacchio (North Adriatic) they range from −0.96 to −1.1 mm/yr. Or in Milano Marittima they range from −0.91 to −1.06 mm/yr. While in Catania (eastern Sicily) vertical rates range from +1.27 to +1.33 mm/yr, At Aci Trezza they range from +1.35 to +1.50 mm/yr.

Therefore, the elevation and geographical knowledge of the maximum LIG marine highstand, as “warmer Interglacial period” than the Holocene (Rovere et al., 2016), constitutes a robust scientific basis to evaluate the future scenarios for the relative sea level rise in the next future, also in the case of an ongoing global warming.

Plotting the displacement rates on the Italian map (Fig. 6 and S2) it is possible to notice how in some Italian coastal areas, both tectonically stable (as Cagliari, Pontina, Fondi, Oristano, Olbia plains) and in tectonic subsidence (as the river Po Plain), the LIG inner margin identified in boreholes extends significantly inland; for example, the LIG inner margin in the Pontina Plain reaches 32 km inland from the present shoreline. This evidence constitutes a great alarm for what may happen in the near future (next 65 years will be 2100). On this topic, detailed maps using high resolution Digital Elevation Model have already been published. In this coastal Plains sea has been flooded using eustatic data (provided by IPCC), Glacial Isostatic Adjustment GIA and vertical tectonic data. These maps have been published starting by Antonioli et al. (2017) and Marsico et al. (2017) for the Po Plain, Cagliari, Oristano and Taranto Plains and by Antonioli et al. (2020) for Fertilia, Valledoria and Orosei Plains in Sardinia, Marina di Campo (Elba island, Tuscany), Granelli and Marsala in Sicily: Tronto, Sangro, Pescara, Lesina and Brindisi Plains on central Adriatic coast. About this topic Deiana et al. (2021) highlighted three different scenarios of flooding for some Sardinian coastal plains and for the Pontina and Fondi coastal plains (about 100 km southern Rome); they correspond to three different age: LIG (118 ka) with an inner margin at 8.2 m, and a flooded area of 397 Km^2, the 2300 IPCC projection at 5.3 m showing a flooded area of 304 km2, the 2100 IPCC projection with a flooded area of 61 Km^2.

5. Conclusions

The LIG highstand in Italy, based on sea level markers of the LIG transgression, is part of a larger project aiming to produce the Quaternary Map of Italy at 1:500.000 scale (METIQ). This review includes 461 sites along the coasts of Italy, providing an insightful picture of the coastline evolution. Indeed, the study of coastal evolution in Italy is informative on specific time intervals and acting processes, with variable accuracy and precision. The displacement rates computed for the LIG markers are average estimates for the interval between 118 ky BP to present day.

The vertical displacements included in, Table S1 S3, when compared with previous databases some differences are identified because they are calculated at 118 ka BP highstand and corrected for glacial isostatic adjustment (GIA).

The distribution of the markers reflects paleogeographic conditions, and their vertical displacement is the result of distinct processes at regional or local scale. In particular, the vertical displacement of the LIG highstand markers is a response to both surface and deep crustal processes and, in the absence of more recent indicators, our data-base and the related map stand as unsurpassed tools for the measurement of the vertical component of the displacement in Central Mediterranean. Moreover, for the first time, the most important inner margins of LIG marine terraces are published in the same map allowing a sovra-regional perspective of the Last Interglacial geomorphological setting.

The elevation of the 461 LIG sea level markers along the coasts of Italy, provides an insightful picture of the Late Quaternary tectonic processes in this sector of the Mediterranean. Fig. S3 is a.kmz file containing the 461 sites on which is possible to click and get the information of Table S1. The vertical displacement calculated by the LIG markers may be dependant by local scale controlling factors, but at regional scale appears consistent with: (i) stability to slow downlift of Sardinia, central northern Tyrrhenian sea, northwestern Sicily, central and southern Apulia; (II) slow to rapid downlift moving north along the Adriatic coast (iii) stability to slow uplift Jonian Apulia (ìv) rapid uplift of the southern Tyrrhenian, Calabrian Jonian coast and southern Sicily.

CRediT authorship contribution statement

Antonioli F.: Conceptualization, Data curation, Formal analysis, writing– original draft, Ferranti F. Methodology, Writing. Agate M. Formal analysis, Alessandra Ascione A.: Formal analysis, Investigation, Cerrone C., Data curation, Formal analysis, writing– original draft, Investigation, De Santis V. Investigation, Deiana G., Investigation, Fontana A. Investigation, Furlani S., Data curation, writing Leoni G. Conceptualization, Data curation, Formal analysis, writing– original draft, Lo Presti V., Data curation, Formal analysis, writing– original draft Guerrieri L., writing– original draft Mastronuzzi G. , Conceptualization, Data curation, Formal analysis, writing– original draft Monaco C. , Formal analysis, writing– original draft Orru P. , Data curation, Pieruccini P. Data curation, Formal analysis writing– original draft, Sulli Formal analysis. Fontana A. dealt with dataset from Veneto, Friuli and Emilia Romagna regions; F. Antonioli F. and P. Pieruccini P. dealt with dataset from Marche and Molise; G. Mastronuzzi and V. De Santis V. dealt with dataset from Puglia and Ionian Basilicata; Agate M., Monaco C. and Furlani S. dealt with dataset from Sicily; Ascione A., Cerrone C. and Ferranti L. dealt dataset from with Campania, Puglia and Basilicata; Orrù P. and Deiana G. dealt with Sardinia; F. Antonioli dealt with dataset from Lazio, Tuscany and Liguria.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2025.109376.

Data availability

A link to the data and/or code is provided as part of this submission.

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