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Estimating recent divergence time in populations of
Podarcis lilfordi (GÜNTHER, 1874) and *Podarcis pityusensis*
(BOSCÁ, 1883) using NAVIONICS SonarCharts™
(a second update)

MARTEN VAN DEN BERG, February 2015

Abstract:

New data on estimated divergence times of the populations of lacertid lizards in the Balearic Islands are provided in this second update of the October 2011 article: [Estimating recent divergence time in populations of *Podarcis lilfordi* \(GÜNTHER, 1874\) and *Podarcis pityusensis* \(BOSCÁ, 1883\) \(VAN DEN BERG 2011\)](#), which received its first update May 2012. In most cases better estimations of divergence times were available by using the NAVIONICS SonarCharts™ webapp.

Introduction

The present day distribution of *Podarcis lilfordi* and *Podarcis pityusensis*, with numerous island populations, is primarily the result of the Holocene sea level rising after the last (Würm) glacial era. In order to get an estimation of the divergence time within these populations of lizards, we depend on two factors: A holocene sea level model and bathymetric depths between the various islands.

In this second update of the 2011 article [Estimating recent divergence time in populations of *Podarcis lilfordi* \(GÜNTHER, 1874\) and *Podarcis pityusensis* \(BOSCÁ, 1883\) \(VAN DEN BERG 2011\)](#), the original holocene sea level model, modified from MORHANGE et al. (2001), SIDDALL et al. (2003) and GRIFFITHS et al. (2009), is used (see Figure 1 and Table 1). All previous bathymetric depths were compared with data available from the NAVIONICS SonarCharts™ webapp (www.navionics.com/en/sonarcharts), and adjusted if necessary.

For a complete introduction and discussion we refer to the [original article](#) (VAN DEN BERG 2011), but it is necessary to emphasize that the holocene sea level model is just a model, and the bathymetric depths provided by the SonarCharts™ webapp are only reflecting ever-changing conditions, as stated in the motto of the webapp. Especially in shallow depth cases, potential changing conditions, like accumulation of sediments, could influence the outcome, consequently being less accurate. Therefore the data given are just indicative, useful to make comparisons, but should not be regarded as absolute data, they still are only an educated guess.

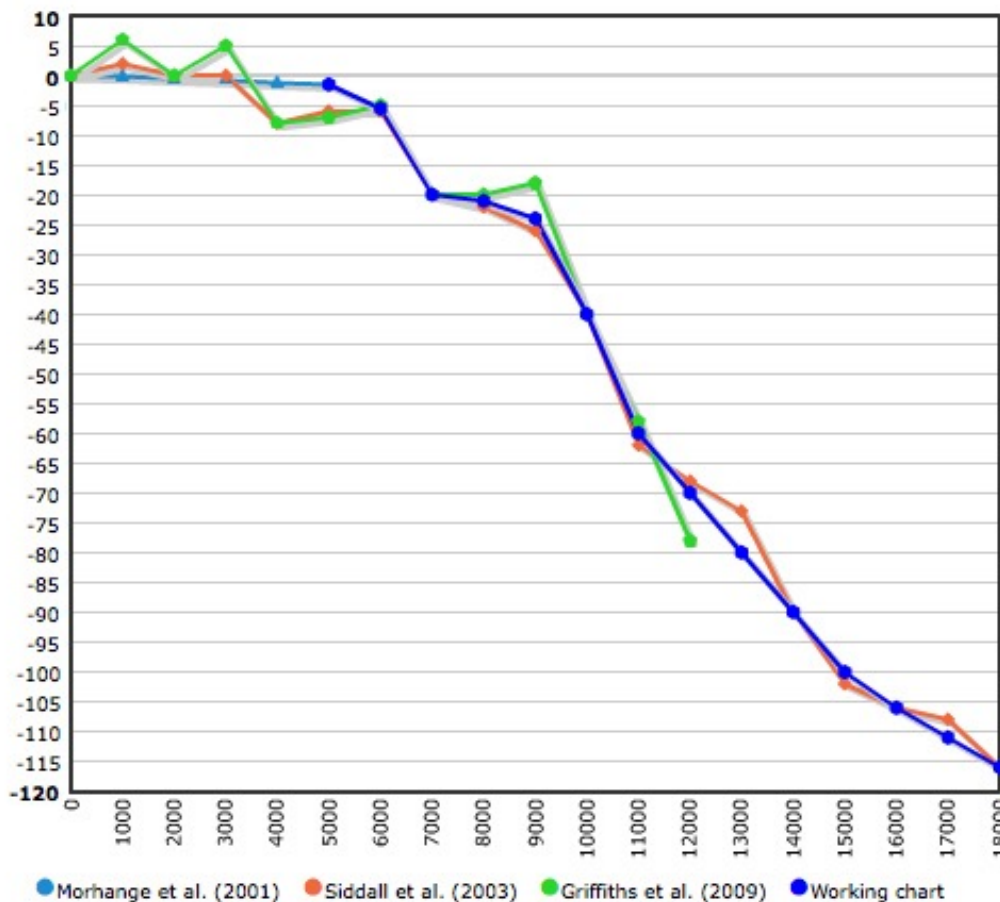


Figure 1. Holocene sea levels in meters compared to present day sea level ranging from present day until 18000 BP, modified from MORHANGE et al. (2001), SIDDALL et al. (2003) and GRIFFITHS et al. (2009). The light-blue Morhange- and blue “Working chart” line were used in determining the estimated divergence times.

Depth	EDT	Depth	EDT	Depth	EDT
0,15	1000	20	7000	47	10350
0,32	1500	21	8000	48	10400
0,50	2000	22	8333	49	10450
1,0	3500	23	8667	50	10500
1,5	5000	24	9000	51	10550
2,0	5125	25	9062	52	10600
2,5	5250	26	9125	53	10650
3,0	5375	27	9187	54	10700
3,5	5500	28	9250	55	10750
4,0	5625	29	9312	56	10800
4,5	5750	30	9375	57	10850
5,0	5875	31	9437	58	10900
5,5	6000	32	9500	59	10950
6	6066	33	9562	60	11000
7	6132	34	9625	61	11100
8	6199	35	9687	62	11200
9	6265	36	9750	63	11300
10	6331	37	9812	64	11400
11	6398	38	9875	65	11500
12	6464	39	9937	66	11600
13	6530	40	10000	67	11700
14	6600	41	10050	68	11800
15	6668	42	10100	69	11900
16	6735	43	10150	70	12000
17	6800	44	10200	71	12100
18	6867	45	10250	72	12200
19	6933	46	10300	73	12300

Table 1. Estimated divergence time (EDT) in years before present related to the present bathymetric **depth** in meters, according to our model modified from MORHANGE et al. (2001), SIDDALL et al. (2003) and GRIFFITHS et al. (2009) as shown in Figure 1.

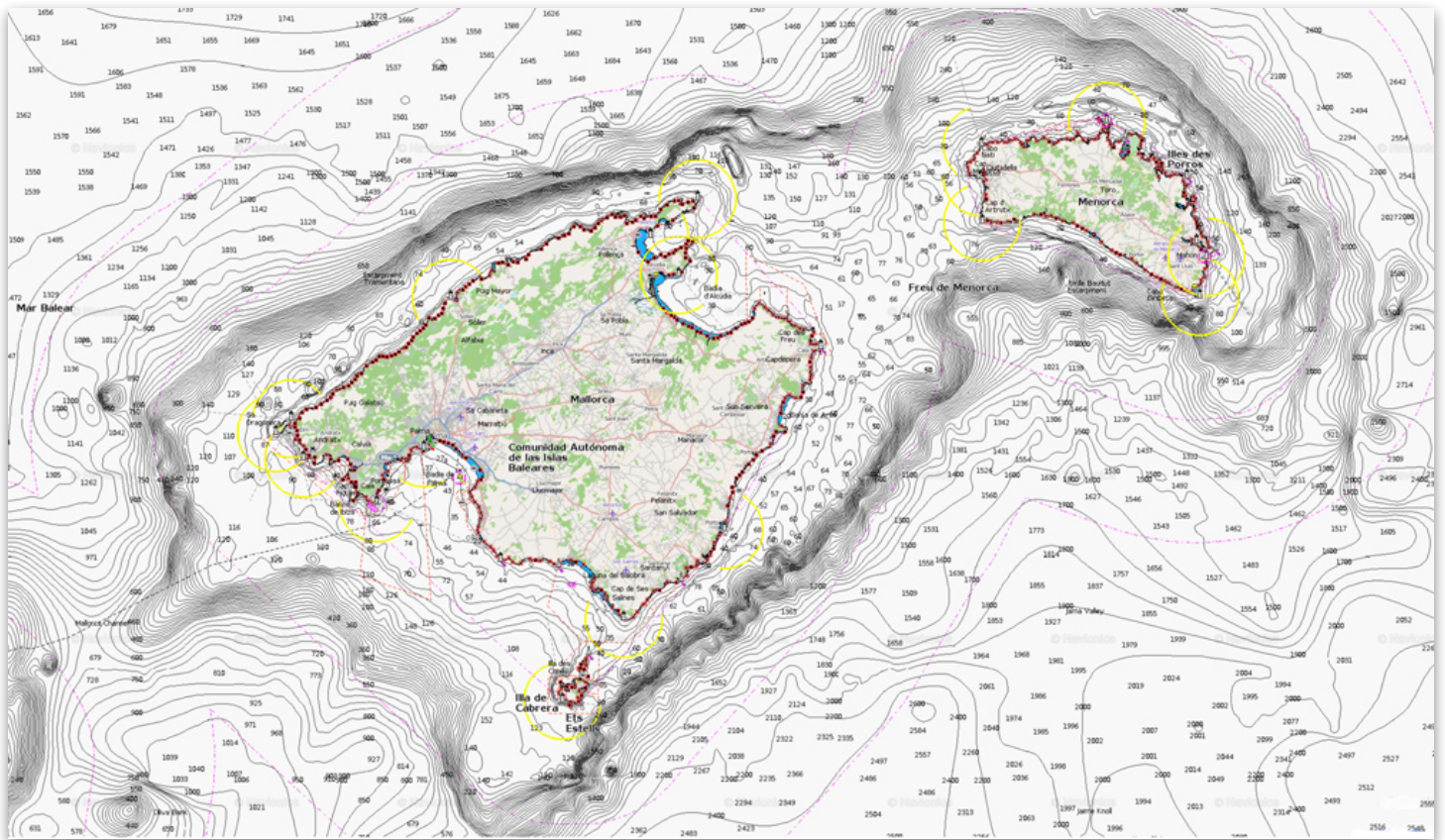


Figure 2. Gran Balearic.

Separation of the main islands

Before we address the current smaller islands, we must remember that during the height of the last glacial era, 18000 BP, Menorca, Mallorca, Cabrera and adjacent present islands were connected in one single island; Gran Balearic. At that time Ibiza, Formentera and adjacent present islands were connected in another single island; Gran Pityusic. The first separation must have occurred between the Mallorca/Cabrera complex and Menorca. The shallowest depth between Mallorca and Menorca is 69 meter, representing an estimated divergence time (EDT) of 11900 years before present (BP).

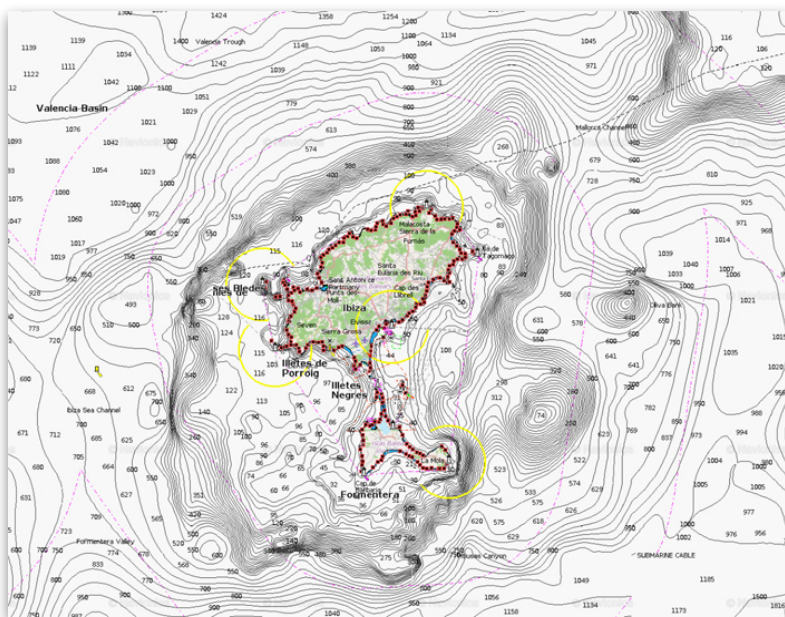


Figure 3. Gran Pityusic.

Separation between Gran Balearic and Gran Pityusic dates from much earlier, the period after the reopening of the Gibraltar strait 5.33 million years ago, known as the Zanclean flood. During all ice ages sea levels did not drop enough to connect both areas again.

Around 1000 years after the separation between Mallorca and Menorca the first present day small islands (or island groups) got separated from the Gran Balearic and Gran Pityusic systems. These will be addressed in order of the oldest separation by complex or island group to the youngest separation, and listed in Table 2-7.

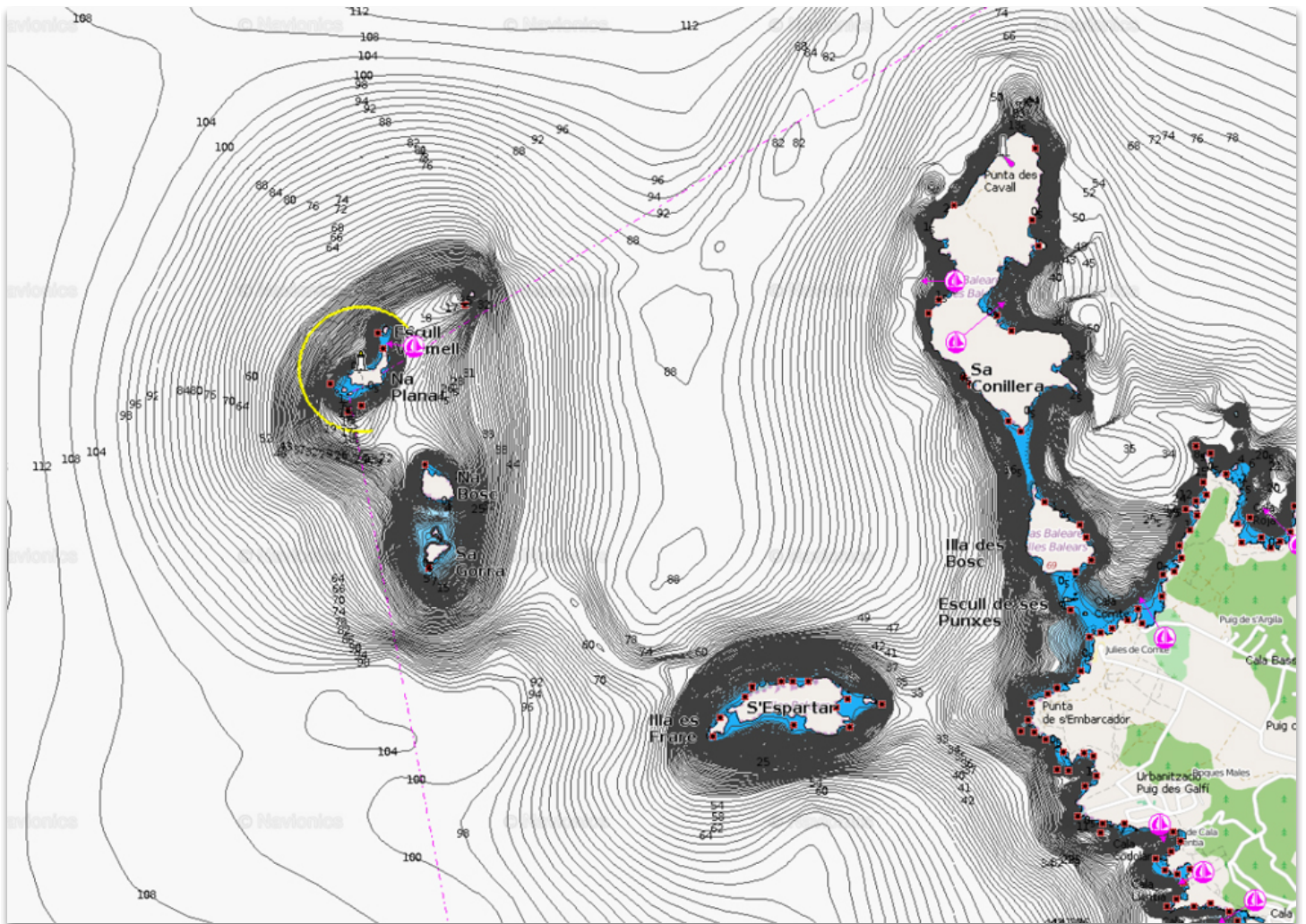


Figure 4. Bledes complex until 10950 BP connected with the Esparatar complex, part of Gran Pityusic at that moment in time.

The Bledes complex as an example

The previous EDT of the Bledes complex from Gran Pityusic (estimated at Illa Bosc de Conillera) was 12600 BP with a bathymetric depth of 76 meter (VAN DEN BERG 2011). Both estimations turned out to be incorrect. According data from the NAVIONICS SonarCharts™ webapp, the shallowest depth between the Bledes complex and Gran Pityusic should be 59 meter, resulting in an EDT of 10950 BP. The interrupted connection with Gran Pityusic must have been at the location of the Esparatar complex (see Figure 4). This will be reflected in Table 2 as “Gran Pityusic (Esparatar)”. Within the Bledes complex separation took place between the Bleda Plana/Escull Vermell/Escull de Tramuntana complex and the Na Bosc/Es Vaixell/Na Gorra complex at 6933 BP (19 m) (see Figure 6). The next separation at 6900 BP (18.7 m) was between the Bleda Plana/Escull Vermell complex and Escull de Tramuntana, followed by the separation of Na Bosc from the Na Gorra/Es Vaixell complex at 5975 BP (5.4 m). Escull Vermell and Bleda Plana separated around 2750 BP (0.7 m), and Es Vaixell and Na Gorra did so in the last 2000 years, having their connection within the 0.5 m bathymetric line.

Bledes complex	Gran Pityusic (Esparatar)	59	10950
Bleda Plana/Escull Vermell/ Escull de Tramuntana	Na Bosc/Es Vaixell/Na Gorra	19	6925
Escull de Tramuntana	Bleda Plana/Escull Vermell	18.7	6900
Na Bosc	Es Vaixell/Na Gorra	5.4	5975
Bleda Plana	Escull Vermell	0.7	2750
Es Vaixell	Na Gorra	0.5	< 2000

Figure 5. The Bledes complex as represented in Table 2.

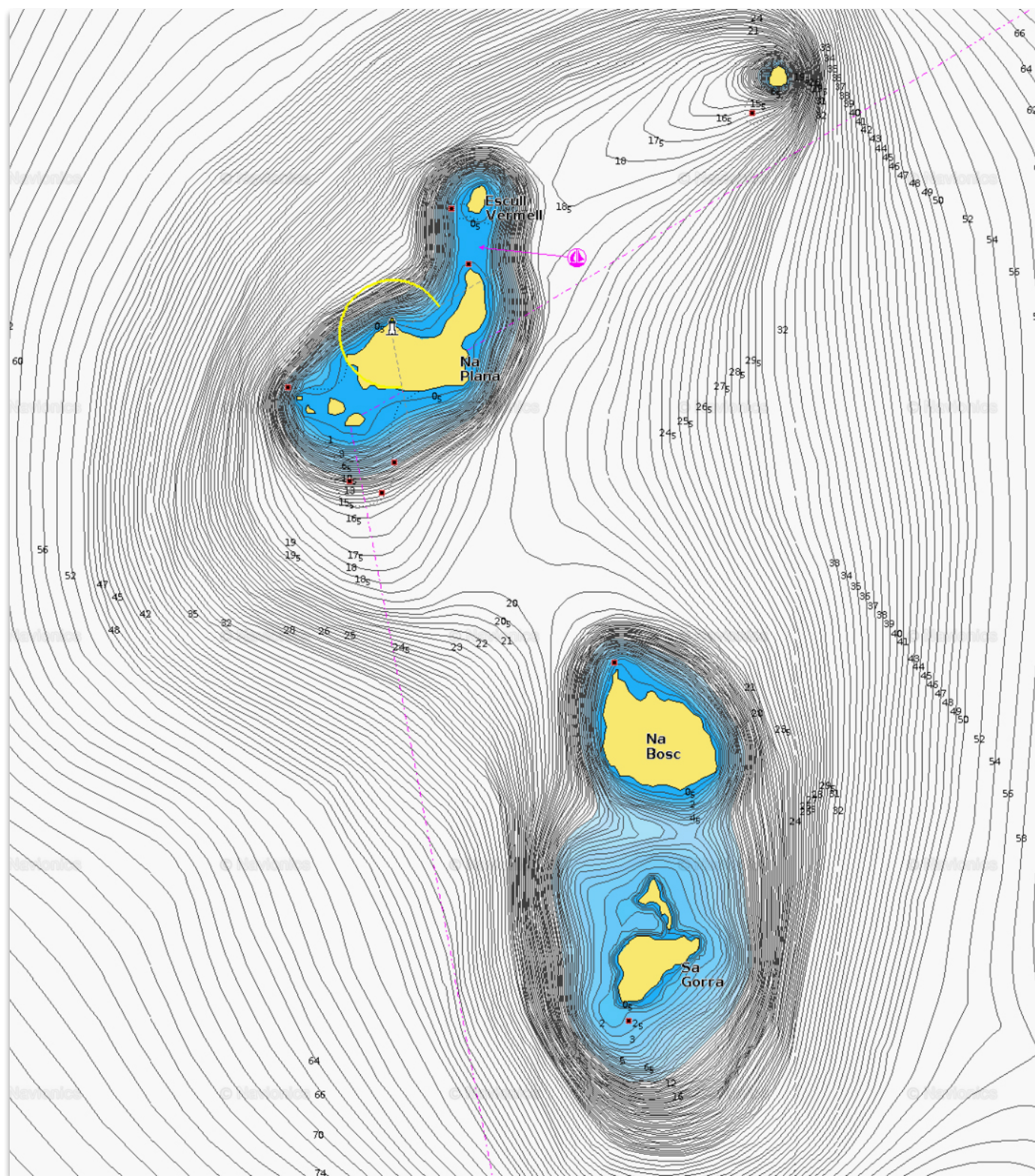


Figure 6. Detail of the Bledes complex.

All further separations within this 0.5 bathymetric line will be listed in the tables as less than 2000 BP, because the large uncertainty makes it impossible to specify more accurate EDTs. During compilation of the tables, there has been chosen, if applicable, to cluster the islands underneath their complex. The cluster separation is more decisive compared to the moment of single island disconnection. This method provides a more pronounced overall picture.

Legend to tables 2-7

2015 = this work. **2011-2012** = original work with the 2012 first update. **CC** (Gran Pityusic) and **PM** (Gran Menorca) are the geological ages in years before present estimated by CIRER COSTA (1986) and PÉREZ-MELLADO (1989). **EDT** = Estimated divergence time in steps of closest 25 years (this work) and in steps of closest 50 years (2011-2012).

Color information is based on the ventral color system discussed and listed in VAN DEN BERG et al. (2014), showing the most frequent color per population in the Gran Pityusic region (Figure 7). For the Gran Balearic region a similar system is provided, discriminating between melanistic and blue-belly non-melanistic populations (blue) and reddish-belly (red) populations.

DD = Data Deficient on color information in our database (www.pityusensis.nl). Color information from the first description of the population or subspecies is provided in stead: Escull Vermell (EISENTRAUT 1930), Es Vaixell (PÉREZ-MELLADO et al. 2014), Espardell (EISENTRAUT 1928), Ses Margalides (MÜLLER 1927a), Murada (EISENTRAUT 1928), Vedranell (MÜLLER 1928), Penjats (EISENTRAUT 1928), Negra Norte (EISENTRAUT 1928), S'Hort (BUCHHOLZ 1954), Cala Salada (MÜLLER 1928), Escull Figueretes (VAN DEN BERG & ZAWADZKI 2010), Canaret (CIRER 1980), Caragoler (EISENTRAUT 1950), Gastavi (EISENTRAUT 1928), S'Estell de Fora and all other Cabrera populations (SALVADOR 1979a), Malgrats and Conills (VON WETTSTEIN 1937), Toro (HARTMANN 1953), Na Pelada (MÜLLER 1927b), Es Colomer (SALVADOR 1979b), Ratas (MÜLLER 1927b) and Bledes on Menorca (PÉREZ-MELLADO 1989).

TL1 = Deliberate translocations on Dau Gran, Es Vaixell and Negra Llevant by EISENTRAUT (1930).

TL2 = Translocated population from Na Foradada on Illa Porrassa (MAYOL 2004).

TL3 = Translocated population of *Podarcis pityusensis* on Illa Sa Torre (VON WETTSTEIN 1937).

PS = *Podarcis siculus*

X = No lizards.



Figure 7. From top to bottom:
Blue = Blue belly lizard.
Purple = Mixed colored lizard.
Red = Red belly lizard.

Separation between		2015		2011-2012		CC	Color	
		Depth	EDT	Depth	EDT	EDT		
Bledes complex	Gran Pityusic (Espartar)	59	10950	76	12600	18000		
Bleda Plana/Escull Vermell/ Escull de Tramuntana	Na Bosc/Es Vaixell/Na Gorra	19	6925	(24)	9000	8500		
Escull de Tramuntana	Bleda Plana/Escull Vermell	18.7	6900	(15)	6650		X	
Na Bosc	Es Vaixell/Na Gorra	5.4	5975	(12)	6450	8500		
Bleda Plana	Escull Vermell	0.7	2750	(6)	6050	8500		DD
Es Vaixell	Na Gorra	0.5	< 2000				TL1	
Dau complex	Gran Pityusic (Malvi Pla)	33	9550	28	9250			
Dau Gran	Dau Petit	22	8325	24	9000		TL1	X
Espartar complex	Gran Pityusic (Ibiza)	32.5	9525	31	9450	9000		
Escui de S'Espartar	Espartar	0.5	< 2000	(6)	6050	6000		
S'Espardell de S'Espartar	Espartar	0.5	< 2000	(6)	6050	6000		
Tagomago	Gran Pityusic (Ibiza)	31.5	9475	25	9050	9000		
Espardell complex	Gran Pityusic (Espalmador)	29.7	9350	28	9250	8000		
Espardell	Espardello	0.7	2750	(3)	5400		DD	X
Ses Margalides	Gran Pityusic (Ibiza)	29.2	9325	(40)	10000	12000	DD	
Vedrà complex	Gran Pityusic (Vedranell)	28.7	9300	(18)	6850	12000		
Es Vedrà	Sa Galera	5.5	6000					X
Esponja	Gran Pityusic (Ibiza)	25.7	9100	25	9050		X	
Escull Llado del Sur	Gran Pityusic (Ibiza)	23.2	8725	23	8500		X	
Murada	Gran Pityusic (Ibiza)	22	8325	(23)	8500	9000	DD	
Escull Llado del Norte	Gran Pityusic (Ibiza)	21	8000	23	8500		X	
Vedranell	Gran Pityusic (Ibiza)	20.5	7500	(18)	6850	12000	DD	
Malvi Pla	Gran Pityusic (Malvi Rodó complex and Rates)	15.2	6675	13.8	6550	7000		
Malvi Rodó complex	Gran Pityusic (Ibiza)	13.2	6550	13.7	6550	8000		
Malvi Rodó	Malvi Esculls	5.7	6025	5.8	6000			X
Santa Eularia complex	Gran Pityusic (Ibiza)	10.2	6350	5.5	6000	7000		
Redona de Santa Eularia	Grossa de Santa Eularia	9.7	6300	6	6050	7500		

Table 2. Gran Pityusic separations.

Separation between		2015		2011-2012		CC	Color
		Depth	EDT	Depth	EDT	EDT	
Gran Ibiza (Penjats)	Gran Formentera (Pou)	9.2	6275	8.3	6200		
Negra Llevant	Gran Ibiza	8.2	6200	5.4	6000	6000	TL1
Negra Oeste	Gran Ibiza	6.7	6125	7.2	6100		X
Canar	Gran Ibiza	5.2	5950	10	6300	7000	
Penjats/Negres complex	Gran Ibiza (Caragoler)	5.2	5950	3.9	5600	6500	
Penjats	Negres complex	4.7	5800	2.5	5250	6000	DD
Negra Norte	Negra Sud	0.5	< 2000	2.5	5250		DD X
Rates	Gran Ibiza	2.2	5150	2.8	5300	< 5000	
S'Hort	Gran Ibiza	2.2	5150	1.4	4700	6000	DD
Sal Rossa	Gran Ibiza	0.7	2750	2.1	5150	< 5000	
Conillera	Gran Ibiza (Bosc de Conillera)	0.7	2750	2.1	5150	6000	
Escull Cala d'Hort	Gran Ibiza	0.7	2750	(6)	6050		X
Petita de Purroig	Gran Ibiza (Grossa de Purroig)	0.7	2750				X
Grossa de Purroig	Ibiza	0.5	< 2000	(2.1)	5150	< 5000	
Cala Salada	Ibiza	0.5	< 2000	(10)	6300	6000	DD
Punta Grossa	Ibiza	0.5	< 2000	(4)	5600		X
Bosc de Conillera	Ibiza	0.5	< 2000	1.9	5100	6000	
Escull Figueretes	Ibiza	0.5	< 2000	1.4	4700		DD
Canaret	Ibiza	0.5	< 2000	1.2	4000	< 5000	DD
Mesquida	Ibiza	0.5	< 2000	(1)	3500	6000	
Caragoler	Ibiza (Escull d'en Terra)	0.5	< 2000	0.9	3250	6000	DD
Escull d'en Terra	Ibiza	0.5	< 2000	0.8	3000		X
Calders	Ibiza	0.5	< 2000	(0.8)	3000	< 5000	
Punta Galera	Ibiza	0.5	< 2000	0.5	2000		

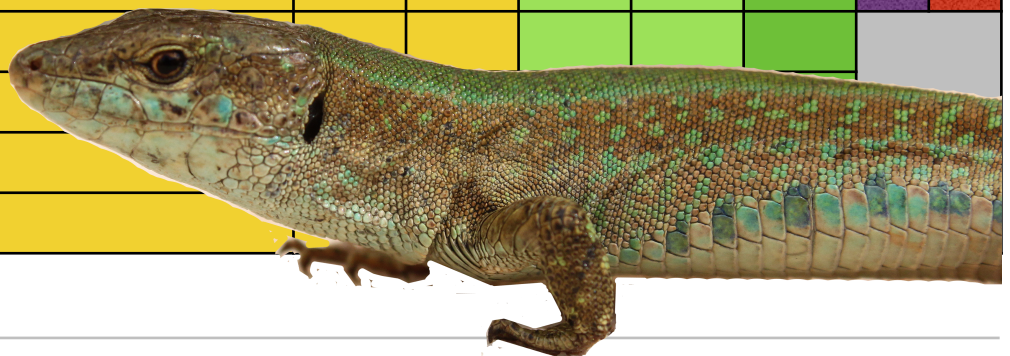


Table 3. Gran Ibiza separations.

Separation between		2015		2011-2012		CC	Color
		Depth	EDT	Depth	EDT	EDT	
Gran Formentera (Pou)	Gran Ibiza (Penjats)	9.2	6275	8.3	6200		
Gastavi	Gran Formentera (Espalmador)	6.7	6125	(8)	6150	6500	DD
s'Alga	Gran Formentera (Espalmador)	1.2	4100	1.4	4700	< 5000	
Torreta	Espalmador/Pou complex	0.7	2750	0.4	1700	< 5000	
Espalmador/Pou complex	Gran Formentera (Trocados)	0.7	2750	0.9	3250	< 5000	
Espalmador	Pou	0.5	< 2000	1.2	4000	< 5000	
Redona de Ses Illetes	Formentera	0.5	< 2000	1.8	5100	< 5000	
Pouet	Formentera	0.5	< 2000	0.1	700		
Ses Perreres	Formentera	0.5	< 2000	0.8	3000		
Fonoll Mori	Formentera	0.5	< 2000	0.8	3000		

Table 4. Gran Formentera separations.



Separation between		2015		2011-2012		Color
		Depth	EDT	Depth	EDT	
Gran Mallorca (Mallorca)	Gran Menorca (Menorca)	69	11900			
S'Estell de Fora	Gran Mallorca (S'Estell d'en Terra)	46.5	10325	(50)	10500	DD
Gran Mallorca (Mallorca)	Gran Cabrera (Na Foradada)	40.5	10025			
Sa Dragonera	Gran Mallorca (Mitjana)	19.7	6975	18.5	6900	
Illot del Sec	Gran Mallorca (Mallorca)	14.2	6600	12.5	6500	X
Mitjana	Gran Mallorca (Mallorca)	12.2	6475			X
Malgrats	Gran Mallorca (Conills)	8.7	6250	8.7	6250	DD
Conills	Gran Mallorca (Mallorca)	7.2	6150	5.1	5900	DD
Porrassa	Gran Mallorca (Mallorca)	6.2	6075	3.6	5500	TL2
Toro	Gran Mallorca (Mallorca)	5.2	5950	1.7	5050	DD
Pantaleu	Gran Mallorca (Mallorca)	4.2	5675	1.5	5000	X
Sa Caleta (Illetes)	Gran Mallorca (Mallorca)	3.7	5550	1.8	5100	X
Na Pelada	Gran Mallorca (Mallorca)	3.7	5550	2	5150	DD
Es Colomer	Gran Mallorca (Mallorca)	2.7	5300	(8)	6150	DD
d'en Salas	Gran Mallorca (Mallorca)	1.7	5050	1	3500	X
Formentor	Gran Mallorca (Mallorca)	1.7	5050	0.9	3250	X
Alcanada	Gran Mallorca (Mallorca)	1.7	5050	0.7	2700	X
Gavina	Mallorca	0.5	< 2000			X
S'Illa de Port de Soller	Mallorca	0.5	< 2000	(7)	6100	X
Na Guardis	Mallorca	0.5	< 2000	1.7	5050	
Na Moltona	Mallorca	0.5	< 2000	1.3	4350	
Sa Torre (Illetes)	Mallorca	0.5	< 2000	1.2	4000	TL3
d'en Curt	Mallorca	0.5	< 2000	(0.8)	3000	

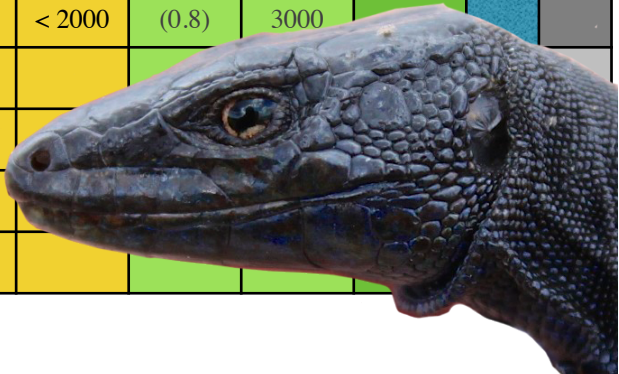


Table 5. Gran Mallorca separations.

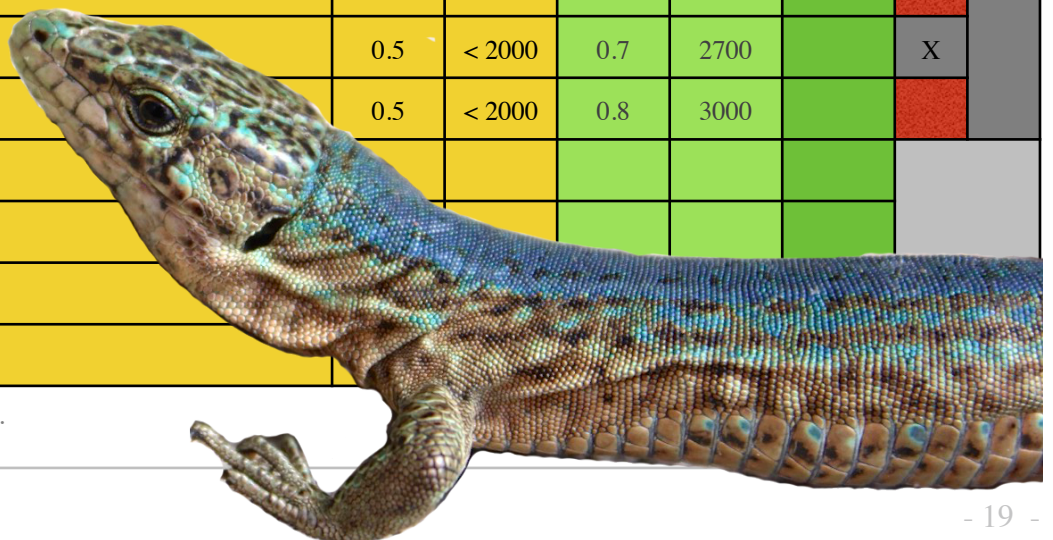
Separation between		2015		2011-2012		Color
		Depth	EDT	Depth	EDT	
Gran Cabrera (Na Foradada)	Gran Mallorca (Mallorca)	40.5	10025	39	9950	
S'Estell des Cols	Gran Cabrera (S'Estell d'en Terra complex)	39.5	9975	44	10200	DD
S'Esponje	Gran Cabrera (Conills)	29.7	9350	28.5	9300	DD
Conills/Plana/Pobra/Foradada	Gran Cabrera (Redona)	23.7	9000	23	8500	
Conills/Plana/Pobra	Foradada complex	20.2	7200	(17)	6800	
Na Foradada	S'Illot de Na Foradada	7.7	6175	(7)	6100	DD
Conills	Plana/Pobra complex	19.7	6975	17.2	6800	DD
Na Plana	Pobra complex	8.2	6200	(5.5)	6000	DD
Na Pobra	S'Illot Pla	5.7	6025	4.3	5700	DD
Redona	Gran Cabrera (Cabrera)	22.7	8450	22.5	8300	DD
S'Estell d'en Terra complex	Gran Cabrera (Cabrera)	10.2	6350	(11)	6400	
S'Estell d'en Terra	El Carabassot de S'Estell d'en Terra	0.5	< 2000	2.4	5200	DD
L'Imperial	Gran Cabrera (Cabrera)	9.2	6275	(17)	6800	DD
Ses Bledes	Gran Cabrera (Cabrera)	5.2	5950	(8)	6150	DD
S'Estell de S'Esclata Sang	Gran Cabrera (Cabrera)	4.2	5675	4.5	5750	DD
Ses Rates	Gran Cabrera (Cabrera)	4.2	5675	(5.5)	6000	DD
Illa des Fonolls	Cabrera	0.5	< 2000	(4)	5600	DD
Illot des Fonolls	Cabrera	0.5	< 2000	(2)	5150	DD

Table 6. Gran Cabrera separations.



Separation between		2015		2011-2012		PM	Color
		Depth	EDT	Depth	EDT	EDT	
Gran Menorca (Menorca)	Gran Mallorca (Mallorca)	69	11900				
Rei	Gran Menorca (Menorca)	10.7	6375	9	6250	7000	DD
Ratas	Gran Menorca (Menorca)	10.7	6375	8.2	6150		DD
Quarantena (Illa Plano)	Gran Menorca (Menorca)	9.7	6300	13	6500		PS
Illa de Porros (Sa Nitge)	Gran Menorca (Menorca)	9.7	6300	6.2	6050	9000	
Aire	Gran Menorca (Menorca)	8.7	6250	6.6	6100	8000	
Ses Àligues	Gran Menorca (Gran d'Addaia)	7.7	6175	7	6100	5000	
Sargantana complex	Gran Menorca (Menorca)	1.2	4100	2.2	5200	6000	
Sargantana	Ravells	0.5	< 2000	1	3500		
Addaia complex	Gran Menorca (Menorca)	1.2	4100	4.5	5750	8000 7000	
Gran d'Addaia	Petit d'Addaia	0.5	< 2000	1.8	5100		
Bledes	Gran Menorca (Menorca)	0.7	2750	(3)	5400	7000	DD
Carbó complex	Menorca	0.5	< 2000	0.9	3250	5000	
Carbó Petit	Carbó	0.5	< 2000	0.9	3250		
Carbó	Carbonet	0.5	< 2000	0.9	3250		X
Colom	Menorca	0.5	< 2000	1.5	5000	6000	
Illot de Porros (Fornells)	Menorca	0.5	< 2000	0.9	3259	6000	
Tosqueta	Menorca	0.5	< 2000	(2)	5150	6000	
Ses Mones	Menorca	0.5	< 2000	1	3500		PS
Binicodrell Gran	Menorca	0.5	< 2000	1.2	4000	5000	
Binicodrell Petit	Menorca	0.5	< 2000	1.2	4000	5000	
Soldat (s'Escudella)		0.5	< 2000	0.7	2700		X
Mel		0.5	< 2000	0.8	3000		

Table 7. Gran Menorca separations.



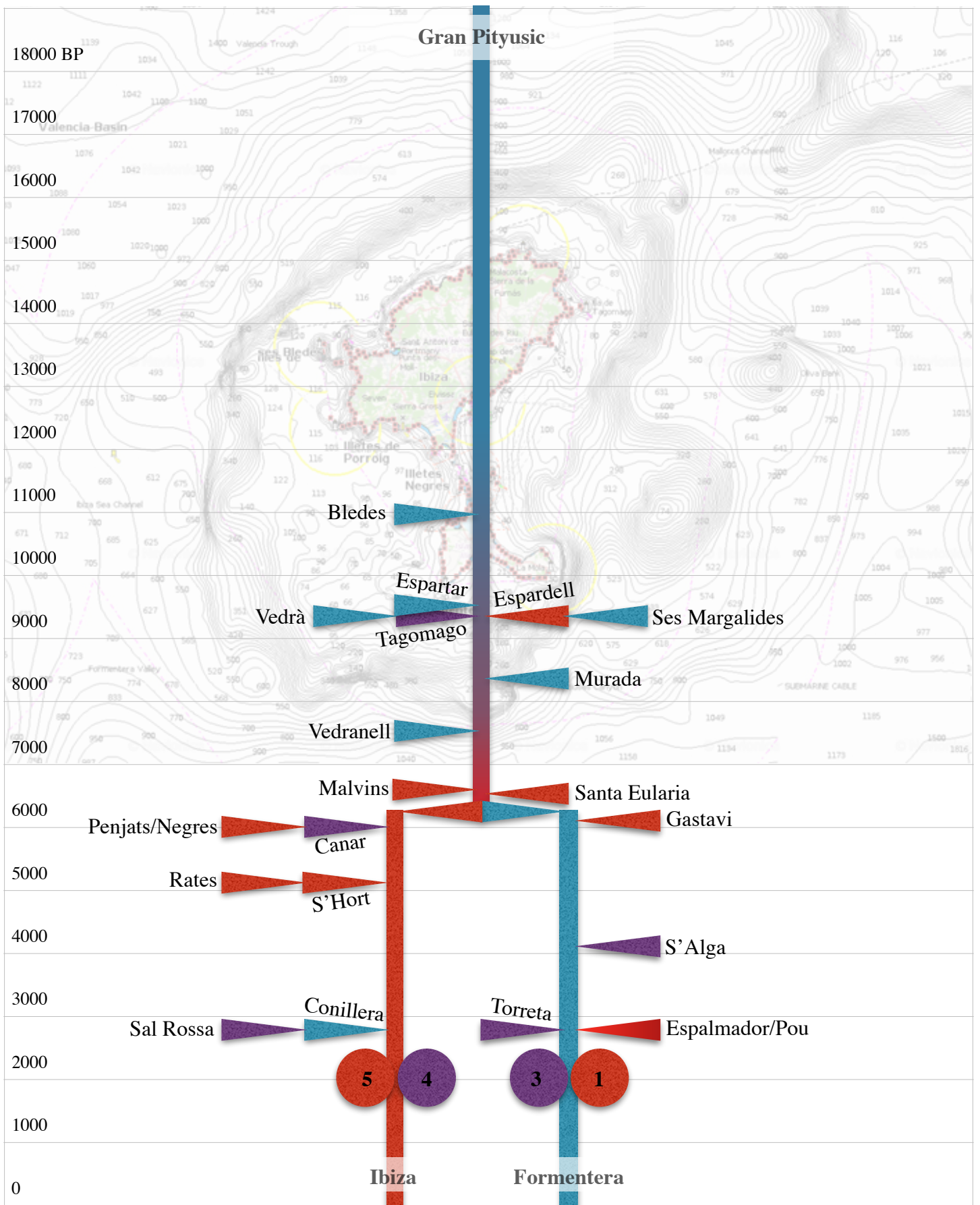


Figure 8. Timeline Gran Pityusic separations.

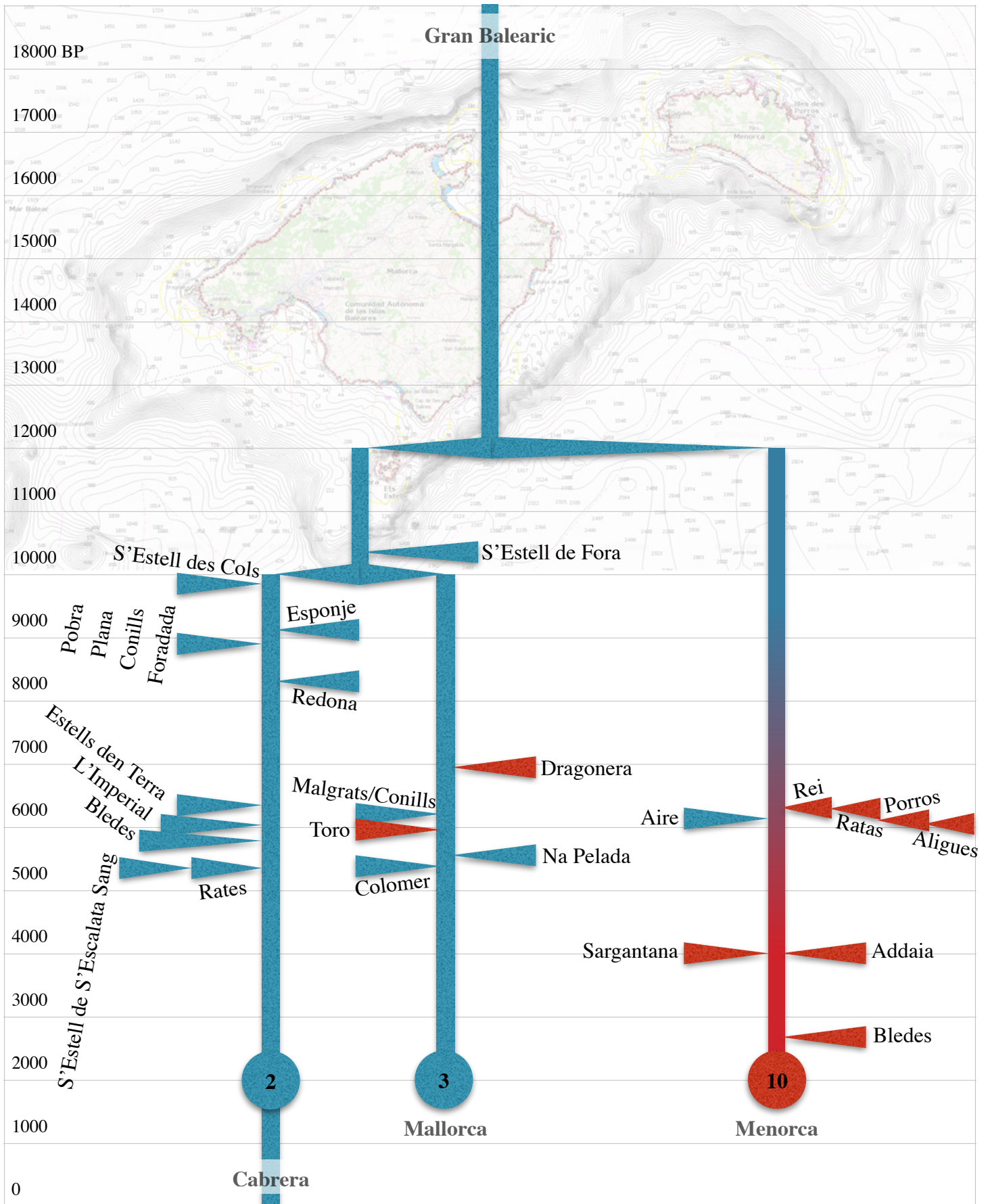


Figure 9. Timeline Gran Balearic separations.

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