Creation Research Society Quarterly 2019 55:142–154.

Is the Alboran Basin, Western Mediterranean, an Impact Crater?

Part I: Kinematics

Michael J. Oard*

Abstract

Understanding the geology and geophysics of the Alboran Sea Basin will contribute toward developing a comprehensive Flood model. In this analysis, I assume the described structural geology is accurate, including the thrust faults. The most unique aspect of the Alboran Sea Basin and the surrounding mountains is an extended, subsided basin surrounded by thrust faults that radially moved away from the basin. According to GPS measurements, this activity took place in an area where the African and Eurasian plates are slowly converging. The thrusts are divided into three zones with local mantle rock, ultrahigh pressure minerals, and diamonds exposed in places, indicating exhumation from depths below 140 km. Geophysical observations indicate the Alboran Basin has thinned crust, a high Moho, a high gravity anomaly, and high heat flow. Seismicity does not form any significant pattern, but unexplained earthquakes continue beneath Granada at 620 to 660 km depth. The geology indicates that after large-scale tectonics, the area was deeply eroded, depositing thick Late Cenozoic sediments in the valleys and basins. Much of the unique geology and geophysics of the area is unexplained by uniformitarian scientists.

Introduction

Geology is one of the main fields secular scientists use to convince people that evolution took place over millions of years. They ignore the overwhelming evidence in biology for intelligent design and believe the real data of history lies in the areas of geology and paleontology. Radiometric dating, along with its many assumptions, is used to support their claims for deep time (Oard, 2019). As a result, the evidence from geology is claimed to trump any claims for a Creator from biology or the Bible.

That is why it is important to develop a biblical explanation for the geological data. Secular geologists have organized the data along secular assumptions, but the inconvenient data have been ignored. Biblical geologists can do better. We need to show that the hundreds of seemingly contradictory data in geol-

* Michael J. Oard, M.S. Atmospheric Science, Bozeman, MT
Accepted for publication December 14, 2018

ogy can be interpreted another way. We also need to develop a comprehensive Flood model to place all the geological observations into a single whole and show that we can explain the geological observations—contrary to what secular scientists claim. At this point in time, we are only in the beginning stages of developing this kind of model. Several models have been presented (Table 1) along with several sub-models (those that attempt to explain certain aspects of the Flood). These models are quite different from one another, and all are in a state of *rudimentary* development. The catastrophic plate tectonics (CPT) model is the most developed with its computer model. It is possible that none of the models is the correct model, or that parts of the models are correct, which are two options included in Table 1. At this point in our knowledge, multiple models are a good thing when there are many unknowns. This agrees with the principle of multiple working hypotheses (Chamberlin, 1890, 1995). We won't know which model is the best unless we continually test each and are able to suggest areas of further research. This is the way model building progresses.

I used the word "rudimentary" above because the models are of a general nature and have not yet been applied to the details of a host of geological challenges. For instance, the geology of the western United States has not been explained well with the Flood models, although the impact/vertical tectonics (IVT) model has been applied with success to some of the geomorphology of the western United States (Oard, 2008, 2013). The hydroplate theory (HPT) has made a poor attempt in trying to explain several of the broadscale features of the southwest United States, including the origin of Grand Canyon (Brown, 2008; Oard, 2016).

In this paper, I will describe the kinematics (the current geological and geophysical features) of the Alboran Sea Basin in the western Mediterranean Sea and the surrounding mountains. In a following paper, I will analyze uniformitarian attempts to explain the origin or dynamics of this unique area and then offer an impact mechanism.

Table 1. The three main Flood models with two other possibilities.

Catastrophic Plate Tectonics (CPT) model
Hydroplate (HPT) model
Impact/Vertical Tectonics (IVT) model
None of the above
Parts of two or more models

Assumptions

Since this is literature research, I must spell out the assumptions I will be making. I will assume that the descriptions of rock units published by secular geologists are accurate. I will not delve into the specific sedimentary rocks or their ages and will assume for the sake of discussion that the geological column in the area represents a true, relative timescale without the millions of years. This paper is mainly a study in structural geology, and so I also will assume secular scientists have given a reasonably accurate description of the structural geology of the area, which is the most significant in determining the origin of the features. Therefore, I will assume that their descriptions of folds, faults, and tectonics are accurate.

More specifically, this means that I will assume that major thrust faults, in which one rock unit pushes up and over another rock unit at less than a 45° angle is accurate (Figure 1). If a thrust fault makes a very low angle with the horizontal, it is called an overthrust, while if the angle is greater than 45°, it is called a reverse fault (Neuendorf et al., 2005, pp. 462, 670). I will refer to all of them as simply thrust faults.

The geophysics of the Mediterranean Sea area and southern Europe can help us understand the area better, but in some cases it is difficult to resolve. Some of the geophysics is straightforward observational data, such as gravity and magnetic anomalies, GPS motions, and heat flow, but some of it is more equivocal, such as seismic deductions. As a first guess, I will assume these aspects of geophysics are true.

Seismic tomography is the determining of the 3D structure of the subsurface by integrating thousands of earthquake waves through a particular volume (Stein and Wysession, 2003). There are many assumptions and problems in this application that makes its accuracy questionable (Foulger et al., 2013). Since seismic observations are sensitive to crustal structure, tomographic images rely on *a priori* crustal structure, including the assumption of high velocity subduction zones (Molinari et al., 2015). This can produce a bias in the results. Regardless of these problems, I will assume the tomographic images are roughly true of the high- and low-velocity volumes in the subsurface.

Thrust Faults and Gravity Spreading

After being skeptical of most thrust faults for many years, I have come to believe,

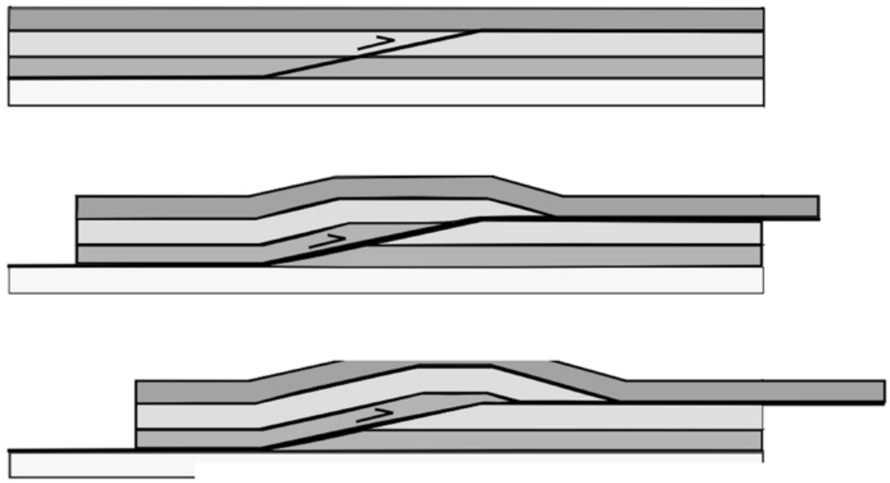

Figure1. Diagram of the origin of a thrust fault (Mikenorton, Wikipedia Commons CC-BY-SA-3.0). A lateral force pushes up older strata over younger strata.

based on field data along the Montana Rocky Mountain front, that the large thrusts I have seen are real, but some of the minor thrusts are imaginary (Oard and Klevberg, 2015). Moreover, a commonsense mechanism presents itself in the case of the Rocky Mountain Front, which can be applied to many other thrusts around the world, and that is gravity spreading caused by uplift of mountains late in the Flood. In the case of the Rocky Mountains, uplift resulted in the slumping of the east edge of the Rocky Mountains eastward, with rock units being stacked up into mostly reverse faults upon hitting a backstop (the High Plains strata). The upward rise of the Rocky Mountains added potential

Figure 2. Aerial view of the multiple thrusts (ridges) along the Rocky Mountain Front with a wide valley to the west, looking north across the Sun River Canyon (Bobak Ha'Eri, Wikipedia Commons CC-BY-SA-3.0). The lake is the Gibson Reservoir, west of Augusta, Montana, USA, and is formed by a dam on the Sun River. The Lewis Overthrust is just out of the figure to the left, west of the wide north-south valley of the Middle Fork of the Sun River.

energy to an unstable edge, which provided the energy for the tremendous horizontal compressive force for gravity spreading. So, one mechanism for thrusting is by gravity on part of a block providing the horizontal push for the thrust sheets (Clarey, 2013). As evidence for gravity spreading, there is a 5 km wide depression or valley between the Rocky Mountain continental divide and the stacks of thrusts (Figure 2). This depression is what one would expect during a rotational slump (see below).

Gravity spreading is the "vertical collapse and lateral spreading of salt and

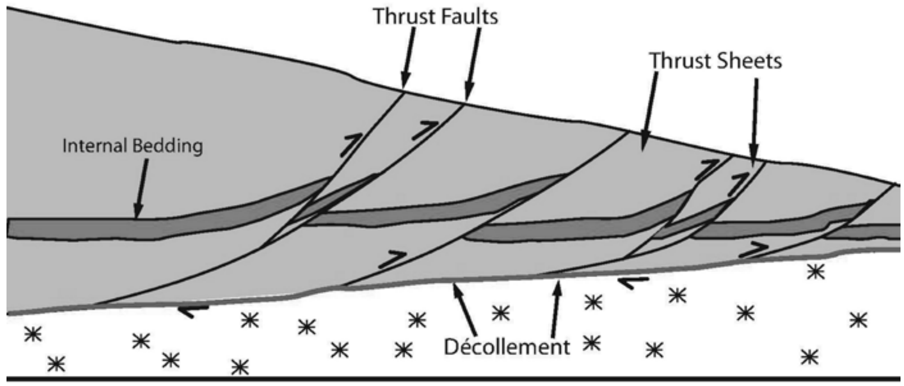

Figure 3. A basal décollement on undeformed rock with imbricate thrust above (Tberli3, Wikipedia Commons Attribution-Share Alike 3.0 Unported). Thrusts caused by compression toward the right side of diagram.

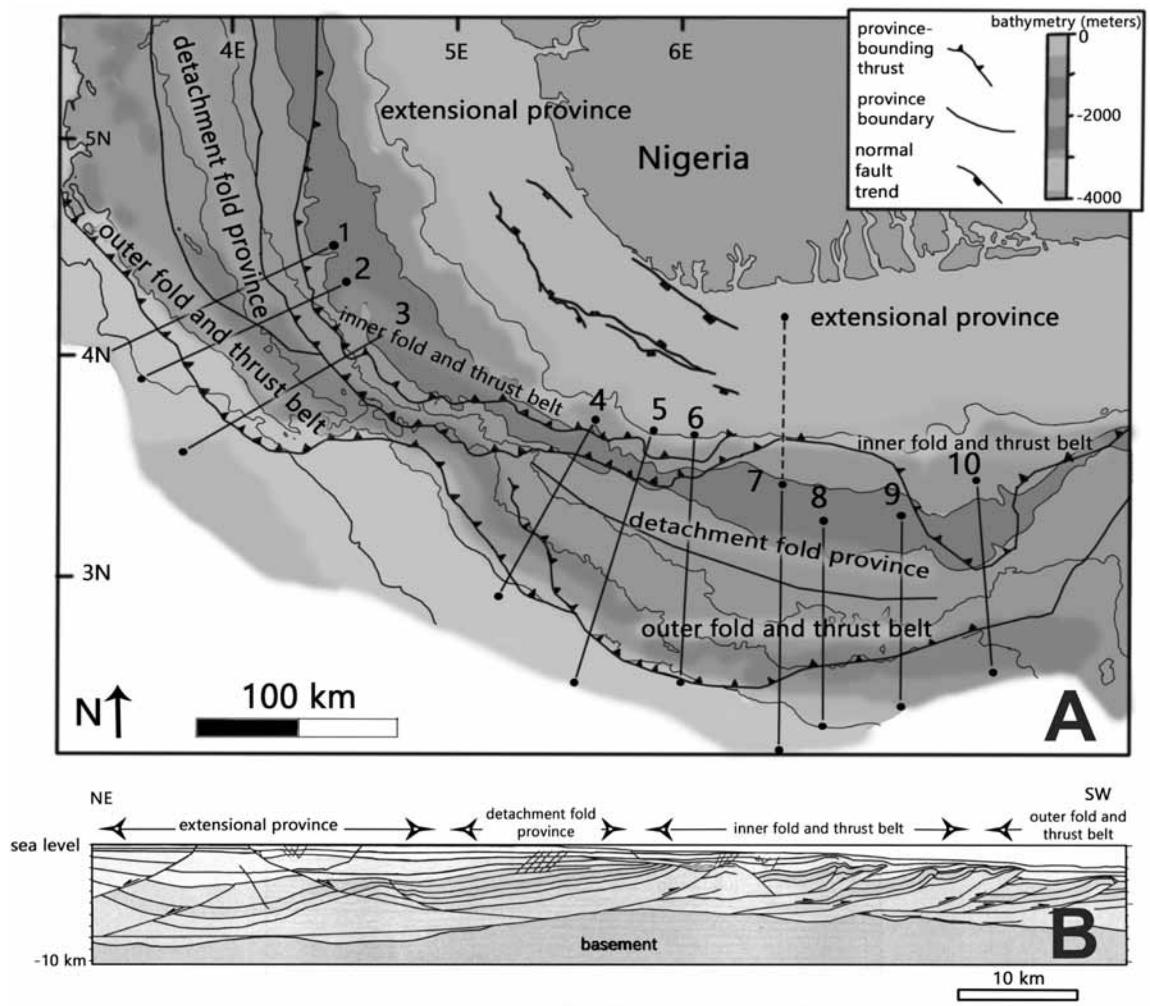

Figure 4. (A) Plan view of the Nigeria continental margin with extensional tectonics and normal faults just offshore with stacked overthrusts from gravity spreading oceanward (from Bilotti and Shaw, 2005). (B) One of the ten cross section through the thrusts shown in Figure 4a (from Bilotti and Shaw, 2005). Notice that the cross section goes from extensional, normal faults just offshore (left) to multiple stacked thrusts oceanward (toward the right). Figures reprinted by permission of the AAPG whose permission is required for further use. AAPG©2005.

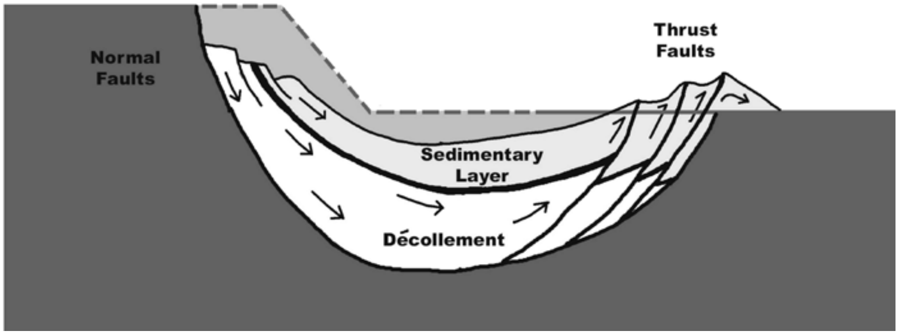

Figure 5. A rotational landslide slump with normal faults at the upper end and thrust faults splaying out from a décollement (redrawn from Melosh, 2013, p. 339, by Mrs. Melanie Richard).

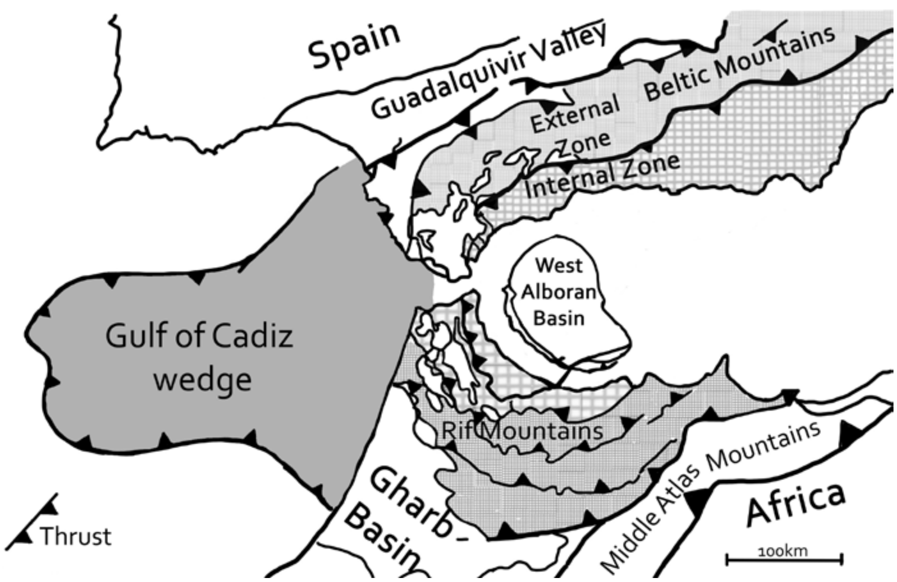

Figure 6. The Alboran Sea Basin in westernmost Mediterranean Sea showing major geological features (Redrawn from Do Couto et al., 2016 by Mrs. Melanie Richard). A few features to point out are the arc-shaped multiple thrusts in the mountains surrounding most of the Alboran Sea with the triangles pointing to the block that moved up and out. Note the internal zones (Alboran Domain) and external zones. Normal and detachment faults not shown.

any overburden under their own weight" (Neuendorf et al., 2005, p. 282). This is similar to what is called "gravity gliding" in that it is the downslope sliding of a mass of rock (Neuendorf et al., 2005, p. 282). The difference appears to be that in gravity spreading, the spreading mass deforms, while in gravity gliding, the block is undeformed.

During gravity spreading, the edge of an uplifted rock slumps down and spreads away on a deep master thrust, called a *décollement*. Above the décollement, slices of rock detach and thrust one on top of another and become stacked as multiple thrusts (Figure 3). We observe these features today by seismic methods along unstable, steep areas, such as along continental margins (Figures 4a and 4b). South of the Kilauea volcano on the large island of Hawaii, the southern edge is slumping down and the outer edge is pushing out into a series of thrust faults. This is called the Hilina slump (Okubo, 2004). The upper part of the mass that spreads shows normal faults downward toward the direction of spreading. It is like a rotation as seen in many slumps (Figure 5). It is not unusual for the area between the normal faults and the stacked thrusts to form a terrace, basin, or valley. In the case of the Rocky Mountain Front, the broad valley west of the thrusts represents the slump valley.

The Alboran Sea Basin and Subbasins

The Alboran Sea is a small sea in the extreme western Mediterranean Sea; and of all the basins in the Mediterranean Sea region and southeastern Europe, it is the most distinctive (Figure 6). The Alboran Sea and surrounding areas form a unique semicircular shape (Torné et al., 2000). The area is one of the most tightly *arcuate* mountain chains in the world (Platt et al., 2013; Kirker and Platt, 1998). To the north are the Betic Mountains of southern Spain (Iberia), arcing toward the west through Gibraltar and swinging southeast as the Rif Mountains of Morocco. The north-south symmetry of the structures and types of rocks between the Betic and Rif Mountains is truly remarkable (Vernant et al., 2010). The internal and external zones of the Betic Mountains continue far to the east in southern Spain, and the same structure of the Rif Mountains generally extends east into northern Africa. The most remarkable aspect of the area is that the surrounding mountains are a stack of thrusts (Figure 7) that were

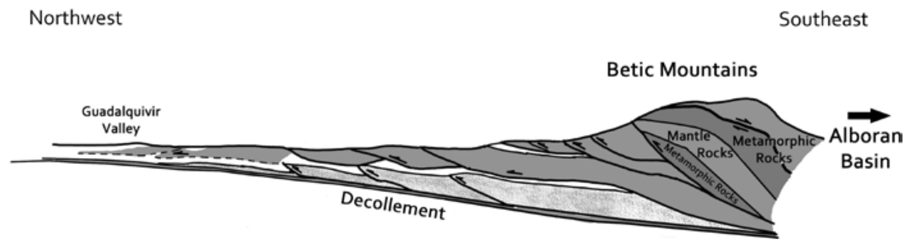

Figure 7. Stack of thrusts spread out northwest from the Alboran Sea (right) (Redrawn from Vergés and Fernàndez, 2012, by Mrs. Melanie Richard).

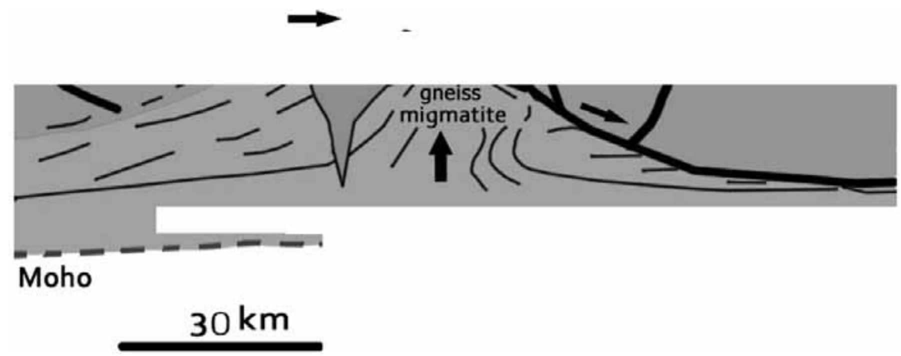

Figure 8. A detachment fault in which a dome of igneous rock (granite) and metamorphic rock (gneiss and/or migmatite) rises and mostly unmetamorphosed rock slides away on a low angle normal fault, called a detachment fault (drawn by Mrs. Melanie Richard).

pushed out from the extended, subsided Alboran Basin.

In the example of the Rocky Mountains stacked thrusts, gravity was the mechanism for the thrusting. But what powerful mechanism could have pushed a vast amount of rock radially out in an arc shape from a developing depression? Secular geology has yet to come up with a good explanation since they believe the thrusting and formation of the depression of the Alboran Basin occurred at the same time and is related somehow, like most else, to plate tectonics. I agree the time is the same. The Alboran Basin is just one example, albeit the best, of many mountains thrusted out from an extending, sinking basin in the Mediterranean region and southern Europe. Moreover, these common extending basins have occurred *within* a convergence zone between the colliding European and the African plates. The current rate of convergence in the Alboran region based on GPS is about 5 mm/yr but not in a north-south direction but more in a northwest-southeast direction (Cunha et al., 2012).

The Alboran Sea is rather complicated (Figure 6 is a simplified diagram). The West Alboran Basin is a deep subbasin that contains sediments greater than 10 km thick (Do Couto et al., 2016; Gutscher et al., 2012). The bottom layers of sediment appear partially chaotic and tilted with debris flows (Do Couto et al., 2016). The majority of the sediment above the bottom layers is mostly undeformed, as if the basin opened up quickly and was rapidly filled in with little subsequent deformation. The central part of the Alboran Sea is uplifted, metamorphic rocks that are similar to the internal zone of the surrounding mountains (Do Couto et al., 2016). Farther east, the small East Alboran and South Alboran Basins contain only a few kilometers and 4 km of sediment, respectively (Medaouri et al., 2014). There is also a narrow North Alboran Basin with several kilometers of sediments. These smaller basins are separated by high areas with thin sediments (Martínez-García et al., 2013). Volcanism has occurred mainly within the eastern part of the basin and the surrounding mountains (Lustrino et al., 2011).

Although most of the Alboran Basin is a result of north-south extension (Do Couto et al., 2016), convergent features are found in the central and eastern part of the main basin (Martínez-Garcia et al., 2013). These convergent features seem to have formed after basin extension (Buontempo et al., 2008).

The Surrounding Betic and Rif Mountains

The Betic and Rif Mountains surrounding the Alboran Basin together are called the Gibralter Arc and are made up of three main zones (Figure 6). Starting from the farthest away, they are the external zone, the middle "flysch" zone (not shown), and the internal zone (Martín-Algarra et al., 2000). "Flysch" is a European term that loosely describes a thick, poorly fossiliferous mixture of bedded rocks including conglomerates, sandstones, fine-grained sedimentary rocks, and limestones (Neuendorf et al., 2005, p. 247). The flysch is mainly found in the western part of the arc and is of minor importance.

All these zones were emplaced by thrusts (Figure 7) that moved radially *outward* from the Alboran Basin as the basin extended (Martín-Algarra et al., 2000; Torné et al., 2000). The radial movement was facilitated especially

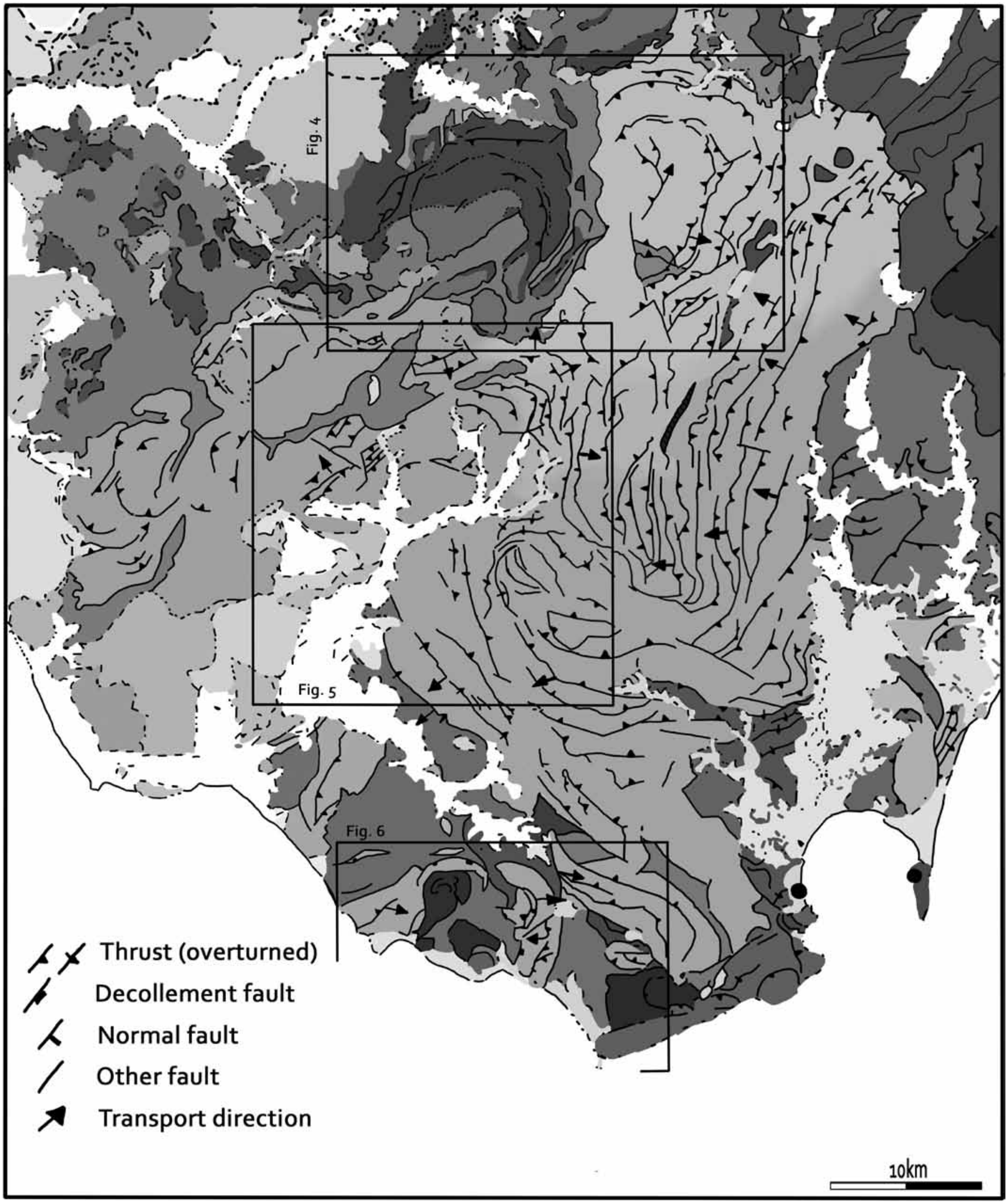

Figure 9. General chaotic pattern of thrusts, faults, and folds from the middle flysch and external zones of the northwest Betic Mountains (from Crespo-Blanc et al., 2012, reprinted by permission of *Journal of the Geological Society, London*). Thrust faults are shown by a line with triangles with the triangle pointing to the upthrown block.

by Triassic "evaporites" (Vergés and Fernàndez, 2012). Then it appears that after the outward thrusting, there was extensional, normal faulting of the internal zone close to the sea and just offshore *back toward the basin* with uplift and detachment faulting (normal and detachment faults not shown on Figure 6) (Crespo-Blanc and Campos, 2001; Do Couto et al., 2016; García-Dueñas et al., 1992; Torné et al., 2000). A detachment fault is the result of an uplift that causes the rocks on top to slide off, in this case back toward the Alboran Sea Basin (Figure 8).

There has also been some extension perpendicular to the direction of thrusting (Mazzoli and Martín Algarra, 2011), as one would expect from thrusts moving out radially, in which case they need to expand perpendicular to the motion. There is also an east-west component of extension in the eastern Betics. Both the north-south and east-west extension opened up valleys and basins that were subsequently filled with sediments (Augier and Jolivet, 2005).

The External Zone

The external zone of the Betic Mountains abuts against the foreland Guadalquiver Basin, and the external zone of the Rif Mountains converges with the foreland Gharb Basin south of the Rif Mountains (Do Couto et al., 2016). The thrust sheets show variations in style based especially on the rock type of the particular thrusted rocks and the nature of the décollement, especially the closer they are to the Guadalquiver and Gharb Basins (Luján et al., 2003). Small-scale arcs in a semi-chaotic pattern with different directions of thrusting and local overturning occur at some locations of the western and central Betics (Crespo-Blanc, 2007, 2008; Crespo-Blanc et al., 2012) (Figure 9). This makes sense when thrust sheets of variable rock type pile up against a "backstop" (the boundary that stops the thrust movement), which may be of variable shape. This situation would cause crumpling of the thrust sheets. The style of the thrusting suggests one rapid event:

> Finally, the possibility of generating oblique structures with a very high degree of obliquity with respect to the main trend during *a single episode of shortening* could be a key process in the complex evolution of the central Subbetic. (Crespo-Blanc, 2008, p. 78, emphasis mine)

The Internal Zone

The internal zone, also called the Alboran domain, is made up of mostly three types of high-pressure, low-temperature metamorphic rocks (Buontempo et al., 2008; Do Couto et al., 2016). Metamorphic rocks are usually related to the depth of burial and in this case are said to have metamorphosed tens of kilometers deep (Vergés and Fernàndez, 2012). Starting from the most metamorphosed in the Betic Mountains and going upward: the Nevado-Filabride complex is composed of eclogite and/or blueschist high-pressure, low-temperature metamorphism at 320°-700°C from depths of 35 to 65 km; the Alpujarride complex (Sebtide complex in Rif Mountains) was metamorphosed at 340°-570°C at depths of 21 to 33 km; and the Malaguide complex (Ghomaride complex Rif Mountains) with low-grade metamorphism from a shallower depth. The Nevado-Filabride complex outcrops on the surface only in the eastern Betic Mountains. It is assumed that the metamorphic rocks were somehow pushed down deeply and then exhumed upward (Vergés and Fernàndez, 2012).

The Gulf of Cadiz

The Rock of Gibraltar and the surrounding area are part of the internal zone, while the external zone swings west of Gibraltar into the eastern Gulf of Cadiz, where a wedge of sediment is located (Figure 10). This wedge is seen by seismology to be chaotic with thrust sheets dipping toward the east and over 10 km thick in the extreme east (Gutscher et al., 2012; Iribarren et al., 2007; Platt et al., 2013). The wedge of sediment thins westward and forms an arcuate shape or double arcuate shape.

The Mantle Rocks

The internal zone also is made up of slabs of mantle rocks, which contain ultrahigh-pressure minerals (UHPm), such as coesite, and microdiamonds (Figure 7) (Van der Wal and Vissers, 1993). In Spain the mantle rocks of the internal zone are called the Ronda peridotite, while in Morocco they are called the Beni Bousera peridotite, and they are similar (Torné et al., 1992). A small patch of UHPm and microdiamonds also exist in extreme southwest Spain (Ruiz-Cruz and de Galdeano, 2013). The Ronda peridotite is considered the largest subcontinental mantle outcrop in the world, covering 450 km^2 (Hidas et al., 2013; Moudnib et al., 2015). The Ronda peridotite is composed of a slab of peridotite 4 km thick at the surface that extends deep into the mantle and widens to about 8 km (Mazzoli and Martín Algarra, 2011). The peridotite is underlain by high-grade metamorphic rocks, including brecciated migmatite, gneiss, and mylonite, which indicate much shearing movement, probably as the mantle rocks were uplifted (Mazzoli and Martín Algarra, 2011; Van der Wal and Vissers, 1993).

The UHPm and microdiamonds imply that exhumation of the peridotite was from below 140 km depth (Hidas et al., 2013; Platt et al., 2003)! It is likely the peridotite is thick and continuous around the Gibraltar Arc, since seismic data indicates a continuous high velocity anomaly down to 24 km (Moudnib et al., 2015). Some think that the origin of the peridotite represents an exhumed lithosphere/asthenosphere boundary that sheared up to the surface at a low angle (Frets et al., 2014; Soustelle et al., 2009).

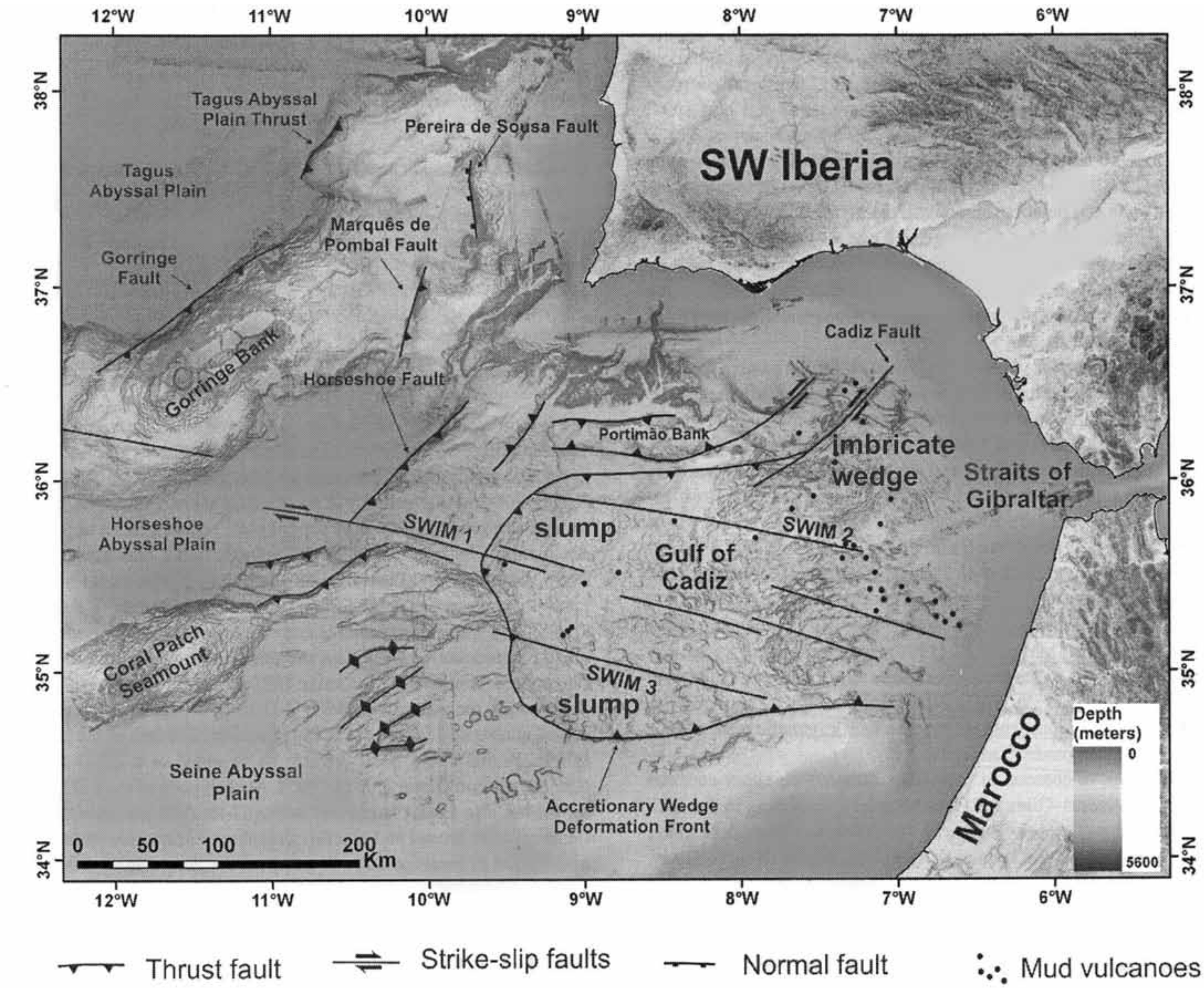

Figure 10. Gulf of Cadiz imbricate wedge thrust faulted west toward the Atlantic Ocean with further sliding down into the deep ocean (from Cunha et al., 2012, reprinted by permission of *Geophysical Journal International*).

Geophysical Observations

Geophysical observations add more information about the subsurface. For instance, seismic waves show that the crust is thinned in the middle of the Alboran Basin with a minimum thickness of 12 km, while the crust thickens to about 36 km in the surrounding mountains (Timoulali et al., 2014; Torné et al., 2000). So, the crust is considered thinned, extended continental crust, probably because it is thicker than the 6 to 7 km, typical of ocean crust but thinner than the 35 km, attributed to continental crust.

Gravity anomalies show a positive anomaly in the center after the lightweight sediments are removed from the West Alboran Basin. Gravity lows exist in the surrounding mountains (Figure 11) (Torné et al., 2000).

The basin also has moderately high heat flow, which increases toward the basin center (Torné et al., 2000). Heat flow is caused by the temperature gradient with depth. Both the gravity anomaly and high heat flow likely result from

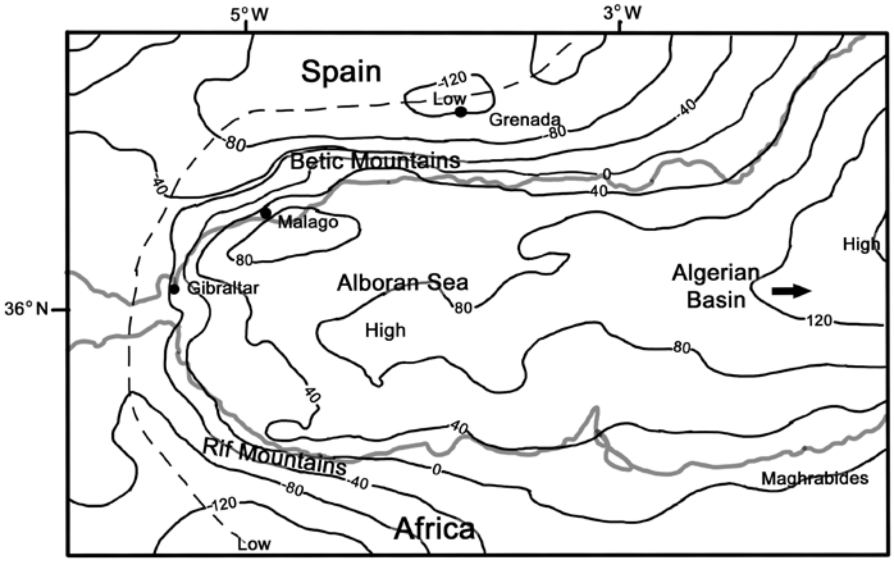

Figure 11. Sediment corrected Bouguer gravity anomalies with contour interval 40 mGal (redrawn from Torné et al., 2000 by Mrs. Melanie Richard). Note the gravity high in the middle of the basin and the lower, arc-shaped gravity anomalies in the surrounding mountains. The gravity high in the northwest Alboran Sea is probably due to the dense Ronda peridotite mantle rocks.

the thinned crust and high Moho, the boundary between the crust and mantle. This allowed hot, denser rocks to have risen to shallower depths.

Seismic velocity varies under the basin. Based on tomography, which is like a CAT scan but using earthquake seismic waves from many directions passing through the area, assuming the anomalies represent temperature anomalies, there is a high velocity anomaly at the top of the crust at 5 to 10 km depth in the Alboran Basin (Timoulali et al., 2014). A low velocity zone occurs in the upper mantle rocks below the basin from about 15 to 60 km (Palomeras et al., 2014; Timoulali et al., 2014). Tomography also shows an image of a near vertical, slightly east dipping, high-velocity layer below the Western Alboran Basin and the surrounding mountains between about 60 to 650 km (Do Couto et al., 2016; Monna et al., 2013; Morales et al., 1999; Palomeras et al., 2014). There are other deep, vertical low-velocity layers in the Gulf of Cadiz to the west.

The seismicity of the region is strange (Casado et al., 2001). Besides the usual shallow earthquakes, there is a north-south cluster of quakes down to 160 km just east of Gibraltar (Bezeda et al., 2013). Then there are no earthquakes from 160 to 620 km (Palomeras et al., 2014). Most mysterious of all are the earthquakes below Granada, and only Granada, in southeast Spain between 620 and 660 km depth that are up to magnitude 7.1 (Gutscher et al., 2012; Palomeras et al., 2014). The first motion of an earthquake is the direction of the first wave from an earthquake to hit the seismometer and gives a measure of the motion of the fault. One solution out of two (there are always two possible directions from the first motion of earthquakes) for the focal mechanism of these quakes is normal faulting on a vertical axis (Casado et al., 2001).

Erosion

After the Alboran Basin extended, and thrusting, normal, and detachment faulting ended, the area was strongly eroded, resulting in mountaintop planation surfaces (Farines et al., 2015) and thick sediments in low areas, much of the sediment likely originating from the currently high areas. Erosion has sheared off the tops of many of the thrust sheets, leaving near vertically tilted strata in places below a gently rolling surface (Figure 12). A measure of the erosion is that all those Late Cenozoic valleys and basins of various types are filled with sediments estimated to be 209,000 km^3 (Iribarren et al., 2009). Iribarren et al.

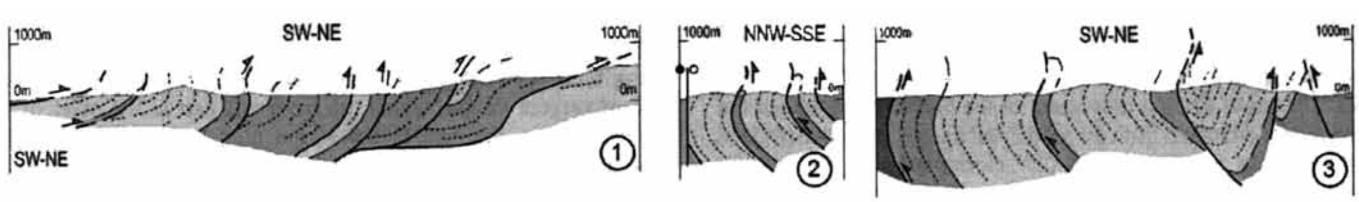

Figure 12. Three cross sections showing the commonly near vertical thrusts, which represent a series of tightly folded synclines and anticlines that used to extend high into the air before erosion reduced them to a gently rolling surface (from Crespo-Blanc et al., 2012, reprinted by permission of *Journal of the Geological Society, London*).

(2009) found over 10 km of sediments in the West Alboran Basins, up to 2 km in the Gulf of Cadiz on top of the thick imbricate wedge (which has over 10 km of sediments), over 2.5 km of strata in the Guadalquiver Valley and the Rharb Basins, and around 400 m average in the valleys and basins in the mountains. Moreover, the intermontane valleys and basins have a fair amount of marine sediments, indicating that much of the area was still underwater during erosion.

Pediments were also carved at low elevations in the valleys and basins of the Betic Mountains (Farines et al., 2015) as the top of the valley and basin sediments were eroded. It is common for sediments that filled basins and valleys to have hundreds of meters of their tops eroded off, leaving erosional remnants (Garcia-Castellanos and Larrasoaña, 2015).

Unexplained by Uniformitarianism

The origin of the Alboran Basin and the surrounding mountains is controversial for secular geologists (Do Cuoto et al., 2016; Torné et al., 2000). Such a feature as outward moving, arc-shaped thrusts from an extending, sinking basin is paradoxical: "The seemingly contradictory observations of a young extensional marine basin surrounded by an arcuate fold-and-thrust belt, [sic] have led to competing geodynamic models (delamination and subduction)" (Gutscher et al., 2012, p. 72). Moreover, the Alboran Basin is an extensional basin in an area of plate convergence based on GPS readings.

In part II, I will delve into the secular hypotheses for the origin of the Alboran Sea Basin and the surrounding mountains and show that an impact origin during the Flood is more plausible.

References

Augier, R., and L. Jolivet. 2005. Late orogenic doming in the eastern Betic Cordilleras: final exhumation of the Nevado-Filabride complex and its relation to basin genesis. *Tectonics* 24:TC4003.

Bezeda, M.J., E.D. Humphreys, D.R. Toomey, M. Harnafi, J.M. Dávila, and J. Gallart. 2013. Evidence for slab rollback in westernmost Mediterranean from improved upper mantle imaging. *Earth and Planetary Science Letters* 368:51–60.

Bilotti, F., and J.H. Shaw. 2005. Deep-water Niger Delta fold and thrust belt modeled as a crucial-taper wedge: the influence of elevated basal fluid pressure on structural styles. *AAPG Bulletin* 89(11): 1,475–1,491.

Brown, W. 2008. *In the Beginning: Compelling Evidence for Creation and the Flood*. Center for Scientific Creation, Phoenix, AZ.

Buontempo, L., G.H.R. Bokelmann, G. Barruol, and J. Morales. 2008. Seismic anisotrophy beneath southern Iberia from SKS splitting. *Earth and Planetary Science Letters* 273:237–250.

Casado, C.L., C.S. de Galdeano, M. Palacios, and J.H. Romero. 2001. The structure of the Alboran Sea: an interpretation from seismological and geological data. *Tectonophysics* 338:79–95.

Chamberlin, T.C. 1890. The method of multiple working hypotheses: with this method the dangers of parental affection for a favorite theory can be circumvented. *Science* (old series) 15:92–96.

Chamberlin, T. C. 1995. Historical essay—The method of multiple working hypotheses, by T. C. Chamberlin, with an introduction by D. C. Raup. *Journal of Geology* 103:349–354.

Clarey, T. 2013. South Fork and Heart Mountain faults: examples of catastrophic, gravity-driven "overthrusts," northwest Wyoming, USA. In Horstemeyer, M. (editor), *Proceedings of the Seventh International Conference on Creationism* (technical symposium sessions). CD. Creation Science Fellowship, Pittsburgh, PA.

Crespo-Blanc, A. 2007. Superimposed folding and oblique structures in the palaeomargin-derived units of the Central Betics (SW Spain). *Journal of the Geological Society, London* 164:621–636.

Crespo-Blanc, A. 2008. Recess drawn by the internal zone outer boundary and oblique structures in the paleomargin-derived units (Subbetic Domain, central Betics): an analogue modelling approach. *Journal of Structural Geology* 30:65–80.

Crespo-Blanc, A., J.C. Balanyá, I. Expósito, M. Luján, and E. Suades. 2012. Crescent-like large-scale structures in the external zones of the western Gibraltar Arc (Betic-Rif orogenic wedge). *Journal of the Geological Society, London* 169:667–679.

Crespo-Blanc, A., and J. Campos. 2001. Structure and kinematics of the South Iberian paleomargin and its relationship with the Flysch Trough units: extensional tectonics within the Gibralrar Arc fold-and-thrust belt (western Betics). *Journal of Structural Geology* 23:1,615–1,630.

Cunha, T.A., L.M. Matias, Pl. Terrinha, A.M. Negredo, F. Rosas, R.M.S. Fernandes, and L.M. Pinheiro. 2012. Neotectonics of the SW Iberian margin, Gulf of Cadiz and Alboran Sea: a reassessment including recent structural, seismic and geodetic data. *Geophysical Journal International* 188:850–872.

Do Couto, D., C. Gorini, L. Jolivet, N. Lebret, R. Augier, C. Gumiaux, E. d'Acremont, A. Ammar, H. Jabour, and J.-L. Auxietre. 2016. Tectonic and stratigraphic evolution of the Western Alboran Sea Basin in the last 25 Myrs. *Tectonophysics* 677–678: 280–311.

Farines, B., M. Calvet, and Y. Gunnell. 2015. The summit erosion surface of the inner Betic Cordillera: their value as tools for reconstructing the chronology of topographic growth in southern Spain. *Geomorphology* 233:92–111.

Foulger, G.R., G.F. Panza, I.M Artemieva, I.D. Bastow, F. Cammarano, J.R. Evans, W.B. Hamilton, B.R. Julian, M. Lustrino, H. Thybo, and T.B.Yanovskaya. 2013. Caveats on tomographic images. *Terra Nova* 25:259–281.

Frets, E.C., A. Tommasi, C.J. Garrido, A. Vauchez, D. Mainprice, K. Targuisti, and I. Amri. 2014. The Beni Bousera peridotite (Rif Belt, Morocco): an oblique-slip low-angle shear zone thinning the subcontinental mantle lithosphere. *Journal of Petrology* 55(2): 283–313.

Garcia-Castellanos, D., and J.C. Larrasoaña. 2015. Quantifying the post-tectonic topographic evolution of closed basins: the Ebro basin (northeast Iberia). *Geology* 43(8): 663–666.

García-Dueñas, V., J.C. Balanyá, and J.M. Martínez-Martínez. 1992. Miocene extensional detachments in the outcropping basement of the Northern Alboran Basin (Betics) and their tectonic implications. *Geo-Marine Letters* 12:88–95.

Gutscher, M.-A., S. Dominguez, G.K. Westbrook, P. Le Roy, F. Rosas, J.C. Duarte, P. Terrinha, J.M. Miranda, D. Graindorge, A. Gailler, V. Sallares, and R. Bartolome. 2012. The Gibraltar subduction: a decade of new geophysical data. *Tectonophysics* 574–575: 72–91.

Gutscher, M.-A., J. Malod, J.-P. Rehault, I. Contrucci, F. Klingelhoefer, L. Mendes-Victor, and W. Spakman. 2002. Evidence for active subduction beneath Gibraltar. *Geology* 30(12): 1,071–1,074.

Hidas, K., G. Booth-Rea, C.J. Garrido, J.M. Martínez-Martínez, J.A. Padrón-Havarta, F. Giaconia, E. Frets, and C. Marchesi. 2013. Backarc basin inversion and subcontinental mantle intracrustal emplacement; kilometer-scale folding and shearing at the base of the proto-Alboran lithospheric mantle (Betic cordillera, South Spain). *Journal of the Geological Society, London* 170:47–55.

Iribarren, L., J. Vergés, F. Camurri, J. Fullea, and M. Fernàndez. 2007. The structure of the Atlantic – Mediterranean transition zone from the Alboran Sea to the Horseshoe Abyssal Plain (Iberia – Africa plate boundary). *Marine Geology* 243:97–119.

Iribarren, L., J. Vergés, and M. Fernàndez. 2009. Sediment supply from the Betic-Rif orogeny to basins through Neogene. *Tectonophysics* 475:68–84.

Kirker, A.I., and J.P. Platt. 1998. Unidirectional slip vectors in the western Betic Cofdillera: implications for the formation of the Gibraltar arc. *Journal of the Geological Society, London* 155:193–207.

Luján, M., F. Storti, J.-C. Balanyá, A. Crespo-Blanc, and F. Rossetti. 2003. Role of décollement material with different rheological properties in the structure of the Aljibe thrust imbricate (Flysch Trough, Gibraltar Arc): an analogue modelling approach. *Journal of Structural Geology* 25:867–881.

Lustrino, M., S. Duggen, and C.L. Rosenberg. 2011. The Central-Western Mediterranean: anomalous igneous activity in an anomalous collisional tectonic setting. *Earth-Science Reviews* 104:1–40.

Martín-Algarra, A., A. Messina, V. Perrone, S. Russo, A. Maate, and M. Martín-Martín. 2000. A lost realm in the internal domains of the Betic-Rif orogeny (Spain and Morocco): evidence from conglomerates and consequences for alpine geodynamic evolution. *The Journal of Geology* 108:447–467.

Martínez-Garcia, P., M. Comas, J.I. Soto, L. Lonergan, and A.B. Watts. 2013. Strike-slip tectonics and basin inversion in the Western Mediterranean: the post-Messinian evolution of the Alboran Sea. *Basin Research* 25:361–387.

Mazzoli, S., and A.M. Algarra. 2011. Deformation partitioning during transpressional emplacement of a 'mantle extrusion wedge': the Ronda peridotites, western Betic Cordillera, Spain. *Journal of the Geological Society, London* 168:373–382.

Medaouri, M., J. Déverchère, D. Graindorge, R. Bracene, R. Badji, A. Ouabadi, K. Yelles-Chaouche, and F. Bendiab. 2014. The transition from Alboran to Alberian basins (Western Mediterranean Sea): chronostratigraphy, deep crustal structure and tectonic evolution at the rear of a narrow slab rollback system. *Journal of Geodynamics* 77:186–205.

Melosh, H.J. 2013. *Planetary Surface Processes*. Cambridge University Press, New York, NY.

Molinari, I., J. Verbeke, L. Boschi, E. Kissling, and A. Morelli. 2015. Italian and Alpine three-dimensional crustal structure imaged by ambient-noise surface-wave dispersion. *Geochemistry, Geophysics, Geosystems* 16:4405–4421.

Monna, S., G.B. Cimini, C. Montouri, L. Matias, W.H. Geissler, and P. Favali. 2013. New insights from seismic tomography on the complex geodynamic evolution of two adjacent domains: Gulf of Cadiz and Alboran Sea. *Journal of Geophysical Research* 188(B4): 1,587–1,601.

Morales, J., I. Serrano, A. Jabaloy, J. Galindo-Zaldívar, D. Zhao, F. Torcai, F. Vidal, and F. González-Loreiro. 1999. Active continental subduction beneath the Betic Cordillera and the Alboran Sea. *Geology* 27(8): 735–738.

Moudnib, L.E., A. Villaseñor, M. Harnafi, J. Gallart, A. Pazos, I. Serrano, D. Córdoba, J.A. Pulgar, P. Ibarra, M.M Himmi, and M. Chourak. 2015. Crustal structure of the Betic-Rif system, western Mediterranean, from local earthquake tomography. *Tectonophysics* 643:94–105.

Neuendorf, K.K., J.P. Mehl Jr., and J.A. Jackson. 2005. *Glossary of Geology*, fifth edition. American Geological Institute, Alexandria, VA.

Oard, M.J. 2008. *Flood by Design: Receding Water Shapes the Earth's Surface*. Master Books, Green Forest, AR.

Oard, M.J. (ebook). 2013. *Earth's Surface Shaped by Genesis Flood Runoff*. http://Michael.oards.net/GenesisFloodRunoff.htm.

Oard, M.J. 2016. *A Grand Origin for Grand Canyon*. Creation Research Society, Chino Valley, AZ.

Oard, M.J., 2019. *The Deep Time Deception: Examining the Case for Millions of Years*. Creation Book Publishers, Powder Springs, GA.

Oard, M.J., and P. Klevberg. 2015. Imaginary uniformitarian thrusts. *Creation Research Society Quarterly* 52:34–43.

Okubo, C.H. 2004. Rock mass strength and slope stability of the Hilina slump, Kilauea volcano, Hawaii. *Journal of Volcanology and Geothermal Research* 138:43–76.

Palomeras, I., S. Thurner, A. Levander, K. Liu, A. Villasenor, S. Carbonell, and M.

Harnafi. 2014. Finite-frequency Rayleigh wave tomography of the western Mediterranean: mapping its lithospheric structure. *Geochemistry, Geophysics, Geosystems* 15:140–160.

Platt, J.P., M.J. Whitehouse, S.P. Kelley, A. Carter, and L. Hollick. 2003. Simultaneous extensional exhumation across the Alboran Basin: implications for the causes of late orogenic extension. *Geology* 31(3): 251–254.

Platt, J.P., W.M. Behr, K. Joahanesen, and J.R. Williams. 2013. The Betic-Rif Arc and its orogenic hinterland: a review. *Annual Review of Earth and Planetary Science* 41:313–357.

Ruiz-Cruz, M.D., and C.S. de Galdeano. 2013. Coesite and diamond inclusions, excolution microstructure and chemical patterns in ultrahigh pressure garnet from Ceuta (Northern Rif, Spain). *Lithos* 177:184–2006.

Soustelle, V., A. Tommasi, J.L. Bodinier, C.J. Garrido, and A. Vauchez. 2009. Deformation and reactive melt transport in the mantle lithosphere above a large-scale partial melting domain: the Ronda peridotite massif, southern Spain. *Journal of Petrology* 50(7): 1,235–1,266.

Stein, S., and M. Wysession. 2003. *An Introduction to Seismology, Earthquakes, and Earth Structure.* Blackwell, Malden, MA.

Timoulali, Y., H. Djellit, Y. Hahou, N. Jabour, and R. Merrouch. 2014. New evidence of delamination in the Western Alboran Sea Geodynamic evolution of the Alboran domain and its margins. *Journal of Geodynamics* 77:206–216.

Torné, M., E. Banda, V. García-Dueñas, and J.C. Balanyá. 1992. Mantle-lithosphere bodies in the Alboran crustal domain (Ronda peridotites, Betic-Rif orogenic belt). *Earth and Planetary Science Letters* 110:163–171.

Torné, M., M. Fernàndez, M.C. Comas, and J.I. Soto. 2000. Lithospheric structure beneath the Alboran Basin: results from 3D gravity modeling and tectonic relevance. *Journal of Geophysical Research* 105(B2): 3,209–3,228.

Van der Wal, D., and R.L.M. Vissers. 1993. Uplift and emplacement of upper mantle rocks in the western Mediterranean. *Geology* 21:1,119–1,122.

Vergés, J., and M. Fernàndez. 2012. Tethys-Atlantic interaction along the Iberia-Africa plate boundary: the Betic-Rif orogenic system. *Tectonophysics* 579:144–172.

Vernant, P., A. Fadil, T. Mourabit, D. Ouazar, A. Koulali, J.M. Davila, J. Garate, S. McClusky, and R. Reilinger. 2010. Geodetic constraints on arctive tectonics of the Western Mediterranean: implications for the kinematics and dynamics of the Nubia-Eurasia plate boundary zone. *Journal of Geodynamics* 49:123–129.