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

Part II: Dynamics

Michael J. Oard*

Abstract

Modern models of the Alboran Sea Basin all assume standard plate tectonics. The area lies at the boundary between the African and European plates, converging since the Cretaceous. This boundary is not clearly seen; it is suggested that northwest Africa is being subducted beneath the Eurasian plate. All of these models have problems, so a Flood scenario is presented that proposes that the Alboran Sea Basin and its surrounding mountains are the result of an impact, based on our knowledge of the area and impact dynamics.

Introduction

In Part I, I described the kinematics of the unique and puzzling Alboran Sea Basin and surrounding mountains, based on structural geology, crustal lithology, and geophysical observations. The most puzzling features are thrust zones radiating from this extensional subsiding basin, especially given the location at a convergent boundary.

Nevertheless, geologists have proposed plate tectonic models of the region that assume that the African and Eurasian plates have been converging for the past 90 million years, destroying the "Tethys Ocean" (Timoulali et al., 2014). GPS measurements show NW-SE movement of about 5 mm/yr (Cunha et al., 2012).

No Clear Plate Boundary in Western Mediterranean

One problem is the absence of a clear plate boundary in the Alboran Sea. At present, the boundary is thought to be in northern Africa, from south of the Rif Mountains eastward into northern Algeria, Tunisia, and then into Sicily along the southern edge of north-dipping thrust faults (Morales et al., 1999; Platt et al., 2013; Vernant et al., 2010) (Figure 1). Although the African plate is supposedly being subducted beneath Europe, it is perplexing because thick, light continental crust is diving beneath thin, dense oceanic crust of the Algerian Sea Basin. It is estimated that nearly 400 km of African crust has been subducted over the past 35 million years (Faccenna et al., 2004). Although earlier plate tectonic models generally precluded the subduction of continental crust beneath oceanic crust (it was once thought

* Michael J. Oard, M.S. Atmospheric Science, Bozeman, MT
Accepted for publication November 18, 2019

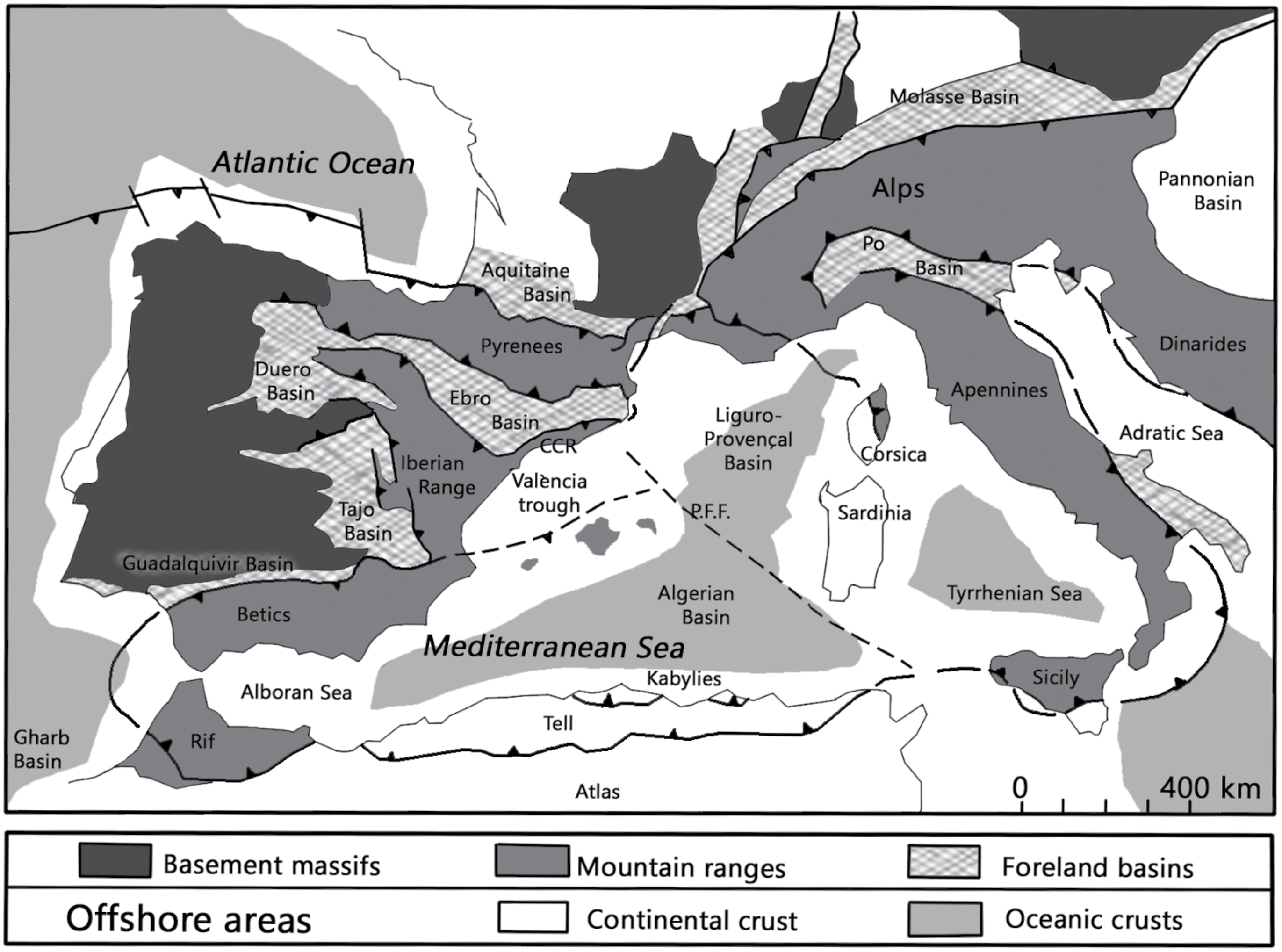

Figure 1. Map of the western Mediterranean Sea and southwest Europe showing thrust zones (triangles point to upper plate). (Copyright Vergés and Fernàndez, 2012, p. 146, and modified by Mrs. Melanie Richard. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.) African/Europe plate boundary is assumed to be the thrust south of the Rif and Tell Mountains.

impossible), more recent models have been *forced* to accommodate it, in order to explain the perplexing existence of ultra-high-pressure minerals (UHP) such as coesite and microdiamonds in many places (Oard, 2006; Ruiz-Cruz and de Galdeano, 2013), including the mountains surrounding the Alboran Sea.

These problems are not necessarily shared by Catastrophic Plate Tectonics (CPT), since other unique processes of the Flood allow non-uniformitarian explanations. CPT proposes a major spreading of both Africa and Europe away from the Americas (Baumgardner, 2003) but does not specially address features of the Mediterranean Basin. Uniformitarian explanations are both published and more tightly constrained by their framework, and advocates of CPT have no need to accept and speed up the establishment plate tectonics ideas.

Complicated GPS Motions

All models must explain the complex GPS data from the region. In addition to an apparent NW-SE convergence of 5 mm/yr, detailed GPS readings appear anomalous (Vernant et al., 2010). For example, the Rif Mountains of northwest Africa show an apparent south motion of 5 mm/yr with respect to the rest of Africa (Figure 2). The Betic Mountains of Iberia show movement W/NW of 1–2 mm/yr with respect to Eurasia, slower and in a direction different from expected convergence. In answer, geologists have proposed two microplates moving west at 2–6 mm/yr with respect to Africa and Iberia (Gutscher et al., 2012), although

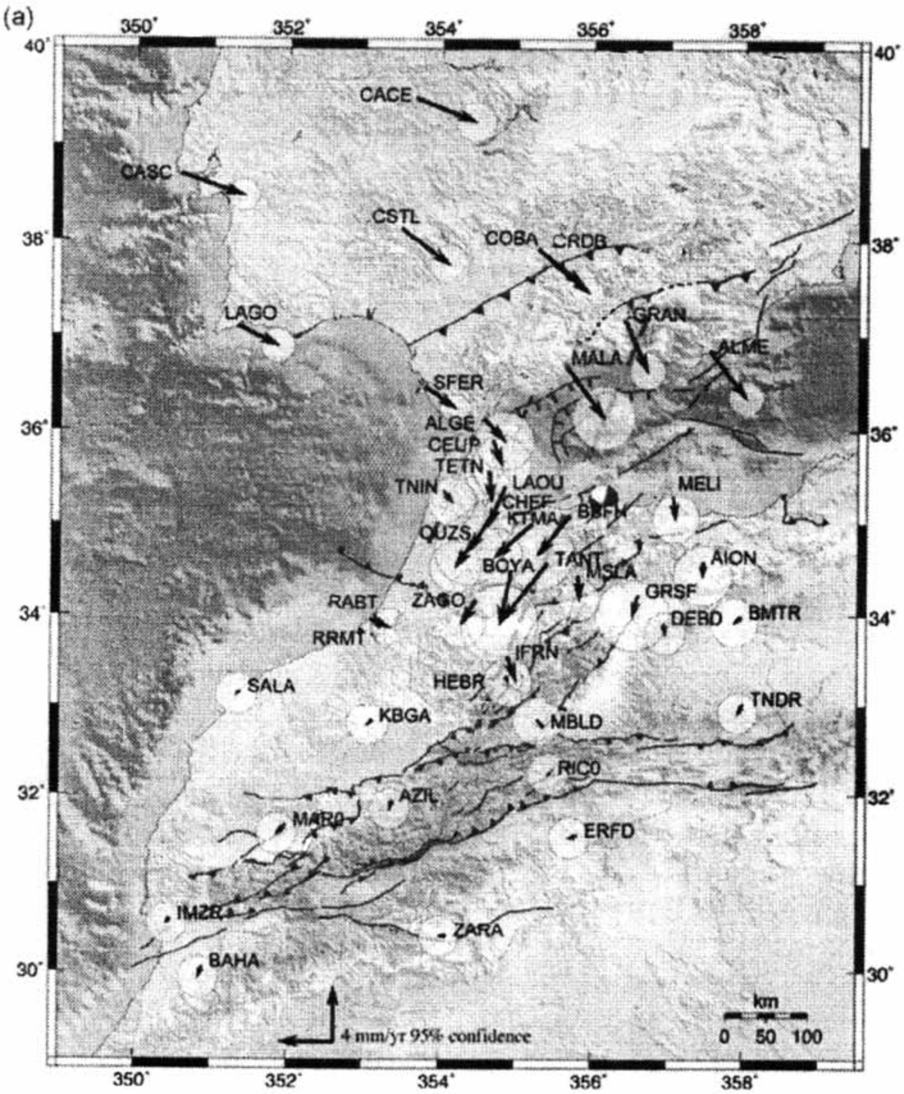

Figure 2. GPS measurements of southern Spain and northwest Africa. (Copyright 2010 from Vernant et al., 2010, p. 125, and modified by Mrs. Melanie Richard. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.) Note anomalous southward motion of about 5 mm/yr in the Rif Mountains.

others suggest a slower rate. But this still cannot explain the southward movement of the Rif Mountains.

Variable and Controversial Hypotheses

Most plate tectonic scenarios are controversial. It is difficult to reconcile plate tectonics and standard orogenic models (Platt et al., 2013), but secular scientists have proposed four major models (Figure 3). Of these, three are less popular.

(1) As the upper mantle grew denser and sank, hot asthenospheric rock upwelled and then moved laterally beneath the Alboran Sea in a process called delamination (Figure 3a) (Timoulali et al., 2014). A variant would have a subducting slab break off in the mantle (Figure 3b) (Vernant et al., 2010), driving asthenospheric rock up and out. If delamination occurred, there should be evidence of mantle flow inward to the area vacated by the sinking upper mantle or tectonic slab, which should show up as seismic anisotropy (Vernant et al., 2010).

The anisotropy of mineral axes can cause seismic waves to travel faster along one axis. Some minerals, like olivine (thought to be a major component of the mantle), are elongated, and if the crystals have been systematically orientated by flow, the mineral exhibits fast and slow directions detectable on seismographs. Anisotropy can also be caused by preferential fracturing, but at depth should not be present. The depth of anisotropy can be difficult to locate, but it probably is in the upper mantle where olivine is the predominant mineral.

"Fast" seismic anisotropy in the Alboran region parallels the Gibraltar Arc, curving with it (Figure 4) (Buontempo et al., 2008). Anisotropy in the Betic and Rif Mountains is thought to represent mantle flow toward the east. There is no such inward anisotropic flow. Some (Mancilla et al., 2015) see this as evidence against delamination; others do not (Timoulali et al., 2014).

(2) Another model proposes that African/Eurasian plate convergence built high mountains in the area. Then these high "Alboran Mountains" collapsed, by the same mechanism seen at the Tibetan Plateau, where edge thinning by normal faulting led to thrusting toward the Himalayas. This provided potential energy that drove gravitational spreading along the thrust arc (Platt and Vissers, 1989). Then the upper mantle sank, causing upwelling of the asthenosphere (Figure 3c) and the concomitant sinking of the Alboran Basin. Though a better theory to explain the basin, there is no evidence of such a mountain range. If such mountains sank, one would expect a thick crust, while the crust is thin with mantle uplift. Thus, there is little excitement for this model today.

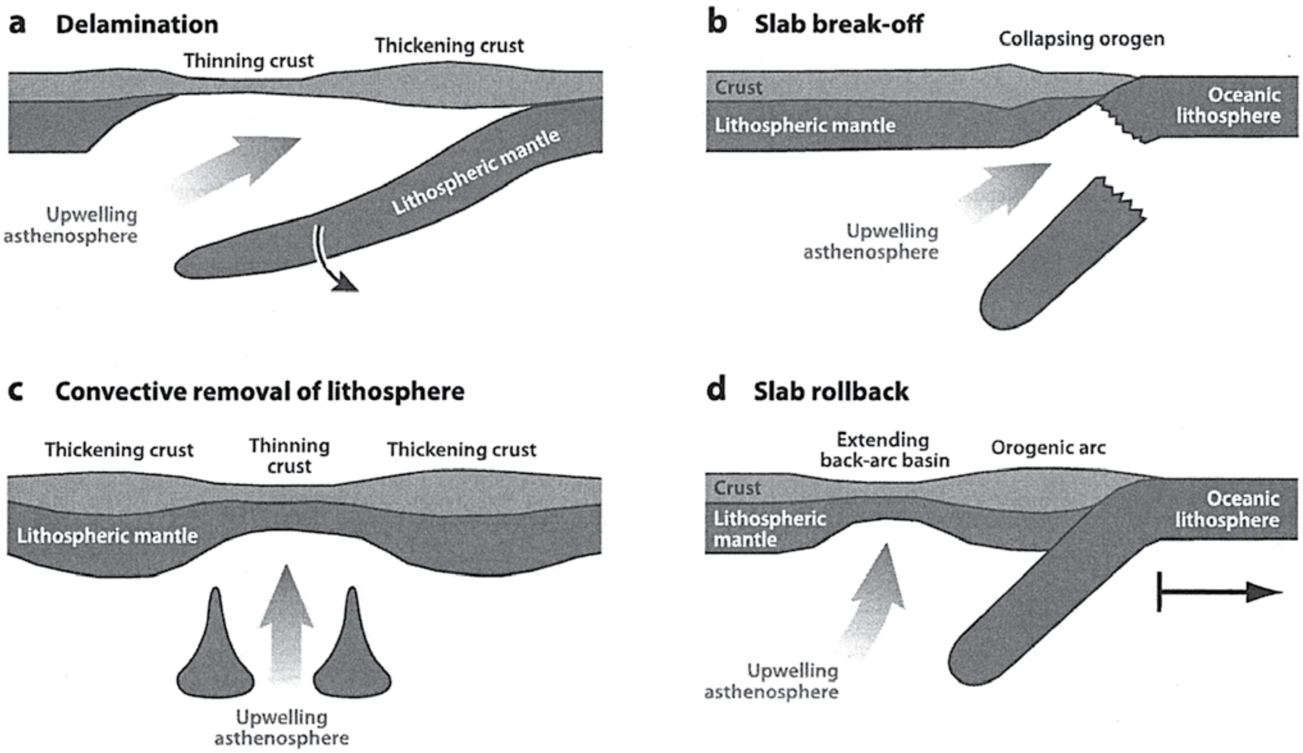

Figure 3. The four main models attempting to explain the unique structural geology of the Alboran Sea Basin and surrounding areas. (Copyright 2013 from Pratt et al., 2013, p. 318. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.).

Most Accept Slab Rollback

The most popular model is the slab rollback model of Gutscher et al. (2012) (Figure 3d). They believe that the plate boundary was located near the southern European coast, 30–35 million years ago (Figure 5), and consisted of a trench, a forearc, and a volcanic island arc (Figure 6). This subducting plate boundary rapidly "rolled back" in the western and central Mediterranean (Figure 5) to its current supposed location (Figure 1). The eastern portion rolled more east to southeast, forming the Tyrrhenian Sea Basin, Apennine Mountains, and the Calabrian Arc, while the western boundary rolled back at first southwest, and then more westward to today's outer boundary of the external zone (Figures 5 and 7) (Do Couto et al., 2016). During rollback, the upper plate extended, forming an unexpected backarc basin at a convergent plate boundary (Figure 3d).

The rollback mechanism relies on gravity pulling a subducting slab toward the Earth's center. Since the slab sinks at an angle, the slab pull force includes a vertical (F_g) and horizontal component (F_h) (Figure 8). Rollback requires the horizontal component. A major problem with this model is mantle displacement, since the slab pull force is weak:

> However, in order to allow the slab to move back, the slab retreat needs that also the mantle of the footwall [descending plate] of the slab moves away in the direction of the slab retreat.... However the slab pull has not the energy to push back eastward [for western Pacific subduction zones] the whole section of mantle located east of the slab in order to allow the slab rollback (Doglioni et al., 2007, p. 156, brackets added).

Thus, rollback requires backward movement of the trench, forearc, and volcanic island arc. There is little, if any, evidence that it has actually occurred. It is based on "backarc" extension (Taylor, 1995), but its proposed action at a convergent plate boundary only adds to the complexity. Both numerical and laboratory models have been attempted, but remain simplistic. Modeled solutions offer little confidence:

> It remains unclear what controls the different styles of backarc and forearc deformation observed on Earth and what drives such deformation. Thus far, numerous conceptual models

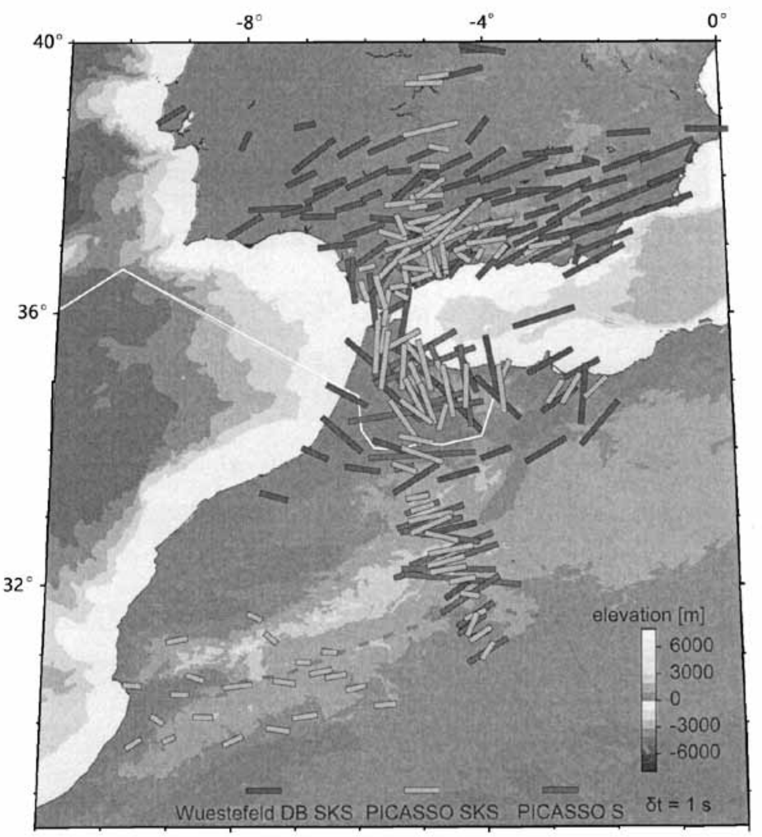

Figure 4. Seismic anisotropy of southern Spain and northwest Africa. (Copyright 2013 from Miller et al., 2013, p. 239. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.) The long axis in the lines show the direction of mantle flow. The light and dark lines are from different methods, which sometimes show different directions in the Rif and Betic Mountains. Bathymetry of the western Gulf of Cadiz show a rapid increase in depth.

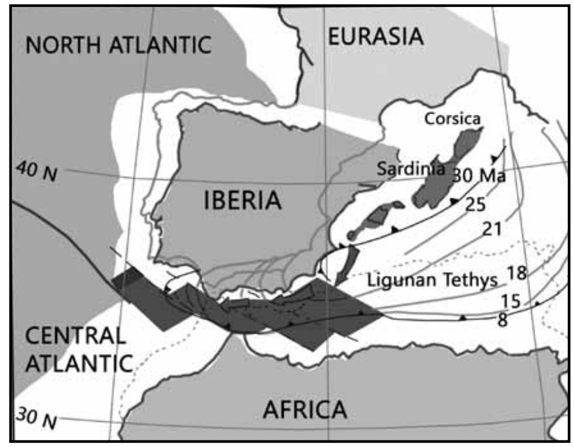

Figure 5. One model for the rollback of the plate boundary near the shore of the northwest Mediterranean Sea at about 30 million years toward the east, south, and west to its position at 8 million years. (Copyright 2012 from Vergés and Fernàndez, 2012, p. 165, and modified by Mrs. Melanie Richard. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.) The current location is shown in Figure 1.

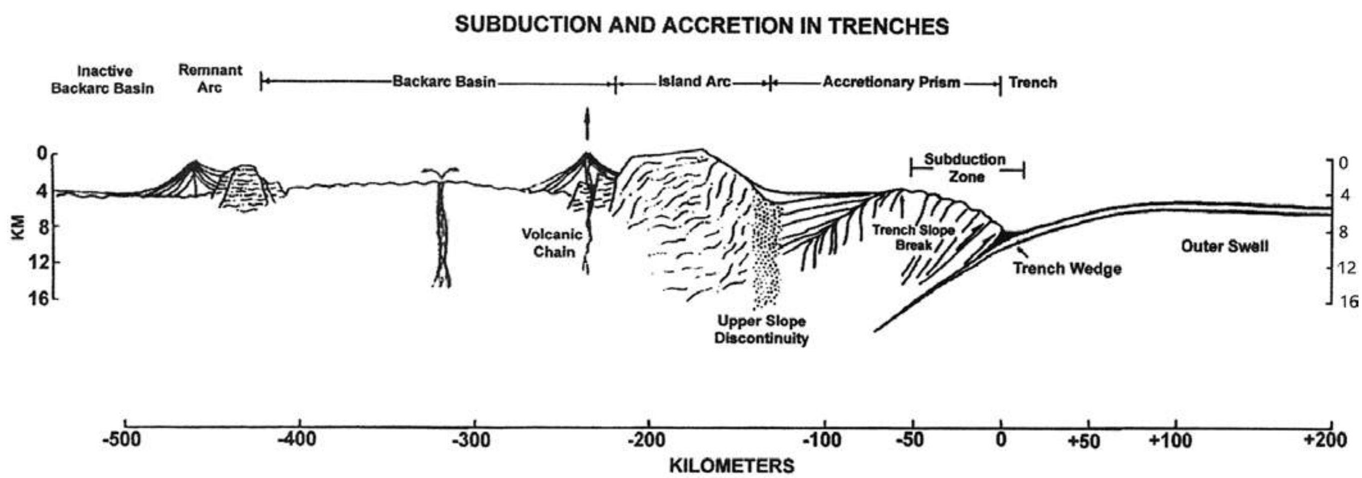

Figure 6. A classic subduction zone/island arc/backarc basin according to plate tectonics (from Oard, 2000). Vertical exaggeration is 5:1.

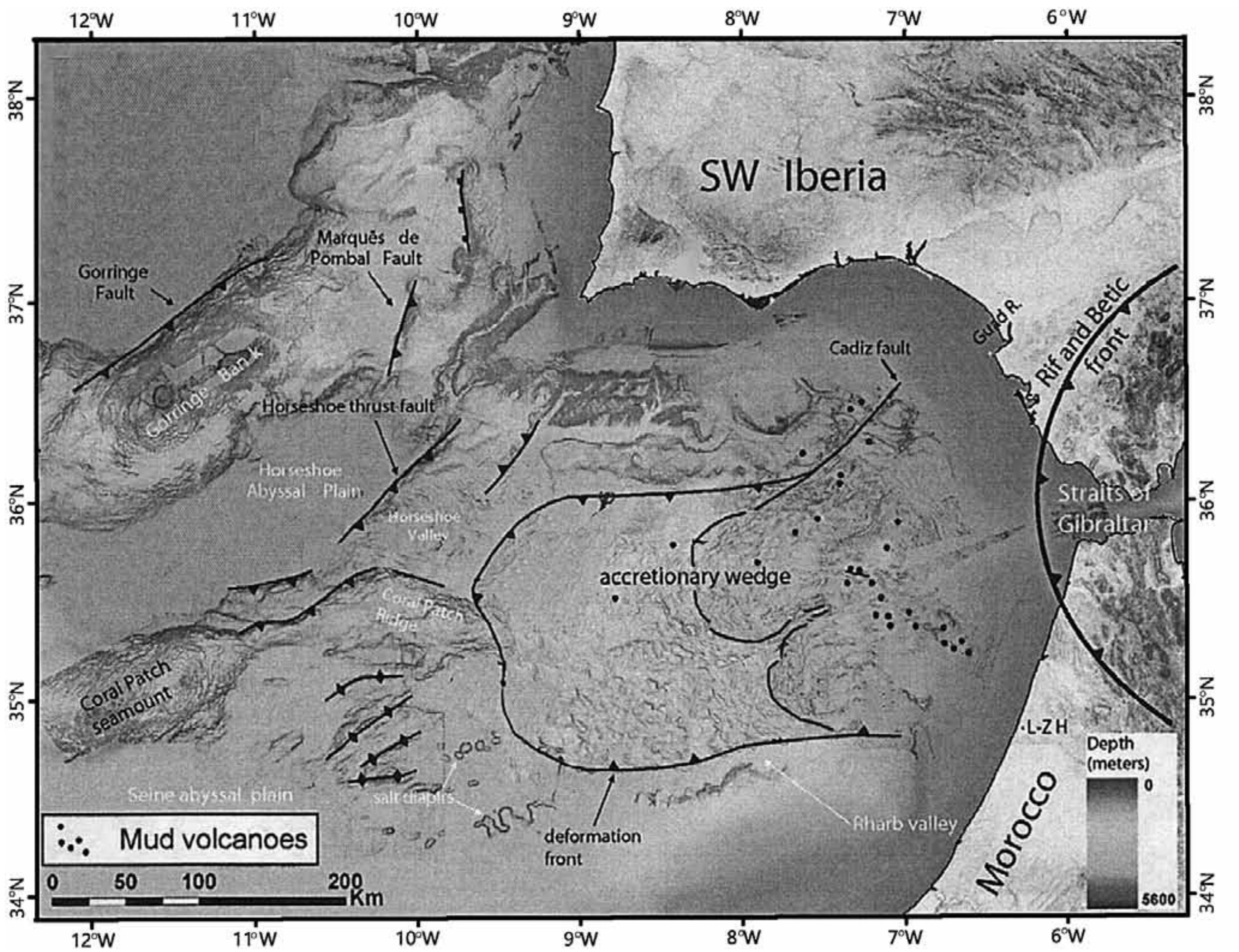

Figure 7. The boundary of the external zone with gravity sliding down into the deep ocean western Gulf of Cadiz. (Copyright 2012 from Gutscher et al., 2012, p. 78, and modified by Mrs. Melanie Richard. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.)

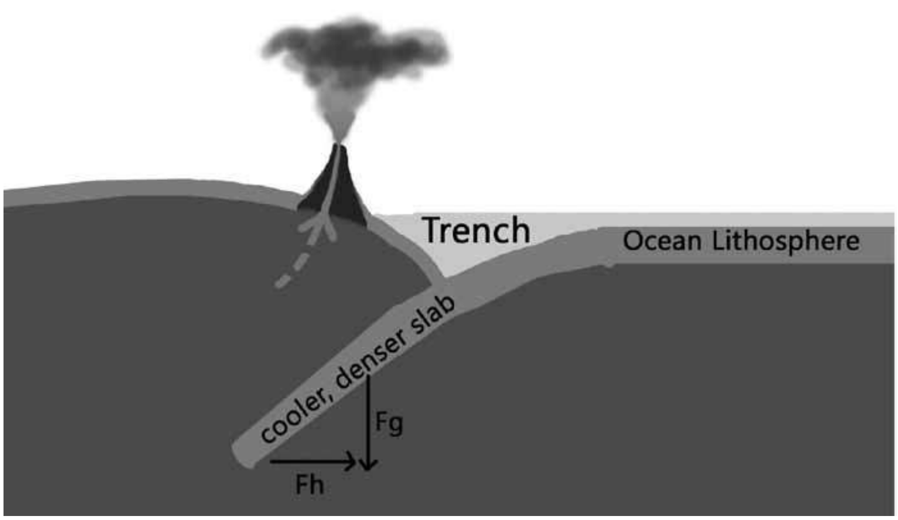

Figure 8 *(left)*. Horizontal and vertical components of the slab pull force. It is Fh that is supposed to cause slab rollback (also called trench or subduction rollback.) Drawn by Mrs. Melanie Richard.

> have been proposed to explain overriding plate deformation at subduction zones, and different physical parameters have been put forward that might control it… (Meyer and Schellart, 2013, p. 775).

Meyer and Schellart (2013) of course believe that their model elucidates the process of slab rollback.

Rollback at the Alboran Basin varies with the particular model. The amount of estimated rollback ranges from 200 to 600 km (Medaouri et al., 2014). Vergés and Fernàndez (2012) propose 800 km! In all the models, during the later stages of rollback, a backarc basin formed in the Alboran Sea as the trench, forearc, and volcanic island arc entered the Gulf of Cadiz. Some models have the Alboran extensional basin forming in situ while others favor its initiation several hundred km east, with the basin itself rolling back to its current location (Vergés and Fernàndez, 2012). If this process occurred, there should be evidence of volcanism all along the path, as well as evidence of a trench, forearc, and volcanic arc in the Gulf of Cadiz. There should also be strong evidence for east-west shearing along the northern and southern boundaries of the westward moving subduction zone, and there is none.

However, none of these features exist in the Gulf of Cadiz, although some researchers theorize a subduction zone based on exposed mantle rocks at the surface (Duarte et al., 2013). Some claim the Gulf of Cadiz imbricate wedge is a forearc accretionary prism (Gutscher et al., 2012). Accretionary prisms supposedly form when dense oceanic lithosphere dives under a less dense plate, and ocean sediments are scraped off, or "obducted" onto the lighter crust, with underthrusts dipping toward the upper plate. In this case, the edge of thrusting should be located in the western Gulf of Cadiz, and it is not. Another problem with the rollback theory is the absence of any discernable connection between the Gulf of Cadiz and the high-velocity slab 60 to 600 km beneath the central Alboran Sea, presumed to be a subducted slab (Figure 9) (Palomeras et al., 2014).

In the 1990s, some interpreted the Gulf of Cadiz stacked thrusts as a giant gravity slide with westward-moving thrusts, and some still do (Platt et al., 2013). Iribarren et al. (2007, p. 97) noted: "We interpret the Gulf of Cadiz Imbricate Wedge as a west-migrating thick thrust system that build up in a relatively short time." This pattern would fit in with the outward thrusting of the external zones of the Betic and Rif Mountains. Debris flows also initiated giant submarine slides that extended down into the deep ocean.

The rollback model remains controversial (Grevemeyer et al., 2015), and some think it happened in the past, but then ceased (Grevemeyer et al., 2009; Mattei et al., 2007). The theory arose to explain *extensional* backarc basins at *convergent* plate boundaries. The dynamics are questionable and there is no consensus on the driving mechanism for long distance trench retreat (Doglioni et al., 2007; Medaouri et al., 2014). Moreover, faulting expected in southern Spain and North Africa from rollback has not been found (Medaouri et al., 2014).

Contrary to Geophysics

Regional geophysical data does not clearly support any model (Dündar et al., 2011; Vernant et al., 2010), and thus, plate tectonics has not been able to adequately explain the region: "The region provides examples of a range of tectonic

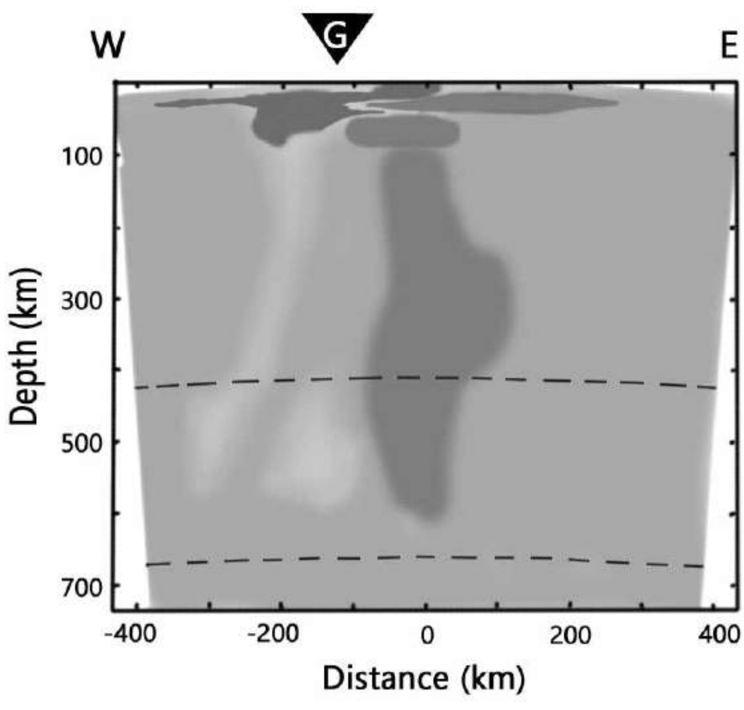

Figure 9. A west-east vertical tomographic image through the Alboran Basin showing the vertical slab of high seismic velocity that starts near 60 km deep and extends to about 650 km. (Copyright 2013 from Bezada et al., 2013, p. 55, and modified by Mrs. Melanie Richard. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.) "G" is the location of the Strait of Gibraltar.

processes that are not predictable from the rules of rigid-plate tectonics" (Platt et al., 2013, p. 313).

The primary problem is the absence of a subduction zone on seismic images, particularly penetrating the 410–660 km transition zone between the upper and lower mantle, and the lack of a resulting explanation for the deep earthquakes below Granada. Most scientists see the Alboran Sea Basin as a backarc basin. However, some think the WAB could be a forearc basin (Do Couto et al., 2016) within an accretionary prism that filled. If so, a trench should be east of the western Alboran Basin and the Gibraltar area should be a volcanic arc, both untrue.

Discussion

So, the Alboran Sea basin shows thin continental crust, radiating thrust sheets, thick sediments, and an internal zone of metamorphic crust with mantle rocks. Many oversimplified and speculative models have been proposed (Medaouri et al., 2014). None have been able to link a subduction zone to the deep earthquakes (Casado et al., 2001; Cunha et al., 2012), which is why various models show subduction zones dipping in *all directions* (Gutscher et al., 2002; Vergés and Fernàndez 2012). No model, even the currently-popular rollback model, predominates: "Several models have been suggested to explain the different tectonic features in this region, but a generally agreed model does not exist yet" (Dündar et al., 2011, p. 1,019). There are still a lot of unknowns (Moudnib et al., 2015), but the structure of the region is becoming clear.

Possible Flood Interpretation

How might this area be caused by the Flood? According to the uniformitarian timescale, basin formation, thrusting, and sedimentation occurred, in the Miocene (Torne et al., 2000). The tectonics and sedimentation were too great to occur after the Flood (Oard, 2014). It follows that the Flood/post-Flood boundary in this region must be in the very late Cenozoic, well after the Miocene, assuming the geological column (Oard, 2014).

Basin subsidence and surrounding uplift, prior to extensive erosion and sedimentation, suggests that the basin began to form near the Zenithic Phase or the Abative Phase of the Retreating Stage of the Flood (Oard, 2008; 2013a; Walker, 1994). This rests largely on the formation of planation surfaces on the tops of the mountains in southern Spain (Farines et al, 2015), which are typical of the Sheet Flow or Abative Phase.

The Alboran Sea Basin and the surrounding mountains show several broad-scale features that are consistent with a large meteorite or comet impact after most sediments (Precambrian, Paleozoic, and Mesozoic) were laid down. Such an impact would have provided the powerful *force* needed to sustain thrusting outward from the basin. The area from which the thrusts pushed up and out could be the center of the crater, now the Alboran Sea Basin. The pre-impact sediments would have resulted from the Inundatory Stage of the first 150 days (Oard and Reed, 2017). The timing of an impact well into the Flood during the Abative Phase would explain the survival of the distinct semi-circular shape and geology around and within the basin. However, there is no other evidence to be observed. Earlier impacts would have been obscured by subsequent tectonics, volcanism, erosion, and deposition.

Features of Impacts

Although many features of impacts are understood, many are not (Melosh, 2013; Oard, 2013b). During impact, a transient, bowl-shaped crater forms within seconds. A rim is formed by the outward and upward push of the sides of the crater (Figure 10), and the crater is quickly modified by sliding and slumping of the inner rim into the crater, expanding the basin diameter by 1.5–2 times while decreasing its depth (Figure 11). With large impacts, the center of the crater usually rebounds, forming a central uplift or central peak ring complex (Melosh, 2013). Rock within the central uplift acts like a fluid (Wünnemann and Ivanov, 2003), oscillating up or down before "freezing" in place. Craters greater than 300 km in diameter can end up with flat floors (Melosh, 2013). From start to finish, the formation of the crater would take less than an hour.

If the central uplift freezes in an up position, a gravity high results from the uplift of denser mantle material, similar to the mascons on the Moon (Wieczorek and Phillips, 1999). The Moho, the boundary between the crust and the mantle, is also elevated. Low gravity usually surrounds the gravity high. If the center falls back, the crater is filled with lighter shattered rock from the impact, sediments, or volcanic rocks, and the center will show a gravity low. Therefore, it is likely a central gravity anomaly, whether high or low, will exist (Searls et al., 2006).

Another feature is thinned crust at the impact. The seismic velocities sometimes measure a high density for this remaining crust, but that is because this crust would be the higher density lower crust after the impact blasted away the upper crust. In addition, impacts fracture rock deep beneath the crater, possibly explaining the low seismic velocity at 15 to 60 km depth. After the crater rim is thrust outward, it will be eroded in subsequent Flood processes, which would make the thrusts more defined with intervening valleys or basins. These valleys and those intermontane valleys and basins formed when extension occurred with rim collapse would fill with sediments.

After one hour, impact craters start to relax, and the bottom of the crater slowly rebounds over time. This process depends on a number of variables, such

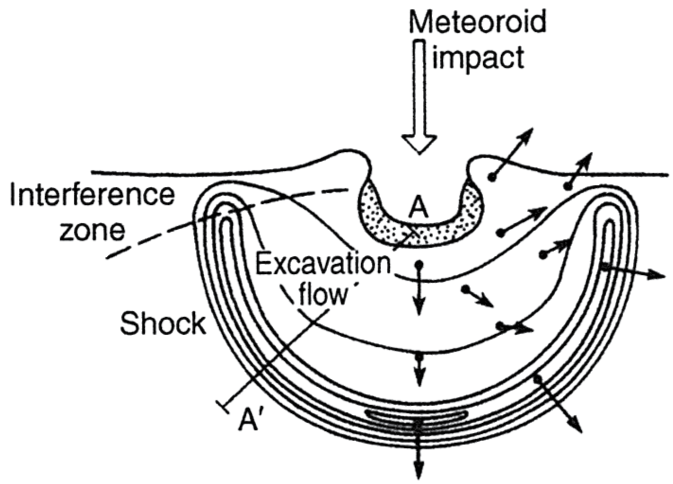

Figure 10. The excavation stage of an impact showing the strong lateral and upward force exerted on the sides of the forming crater. (Copyright 2013 from Melosh, 2013, p. 236. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.) If post-impacting erosion is superimposed on the image, the rim area would be mountainous with multiple thrust sheets, as seen in the Betic and Rif Mountains.

as the temperature of the surrounding rock, whether the center is a gravity high or gravity low, the viscosity of the mantle, the size of the crater, whether there was a phase change in the mantle rocks, etc. (Robuchon et al., 2011).

Suggested Impact Scenario for the Alboran Basin and Surrounding Mountains

If an impact occurred in the Alboran Sea during the Flood, its effects would have been significant and left some evidence. It would have caused thrusting of the Betic and Rif mountains, even as the thinned crust would have formed the subsiding basin. Residual motion continues; the Rif Mountains are still moving south away from the Alboran Basin by continued thrusting (Figure 2).

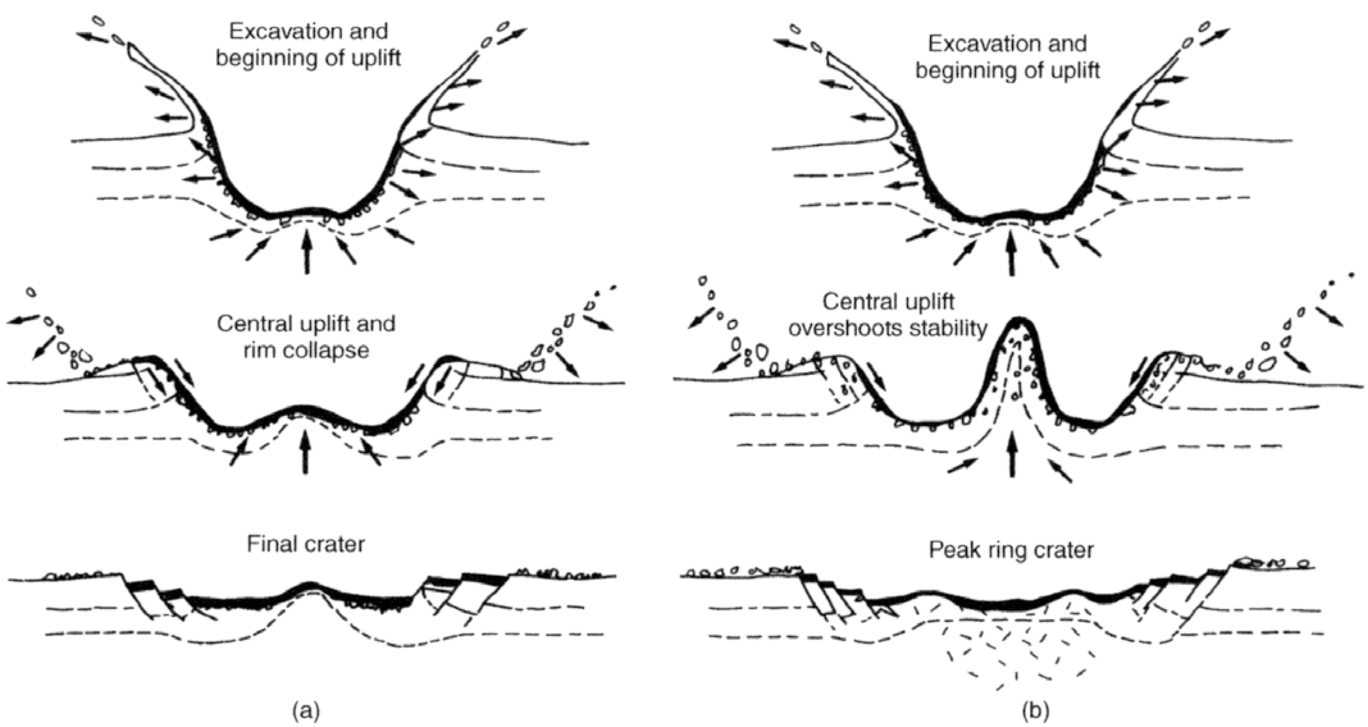

Figure 11. The formation of a complex impact crater which results in either a central peak (a) for small complex craters or a peak ring (b) for large complex craters. (Copyright 2013 from Melosh, 2013, p. 240. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.) Notice that the rock is first pushed outward during the formation of the transient crater and then the sides of the rim slump back into crater.

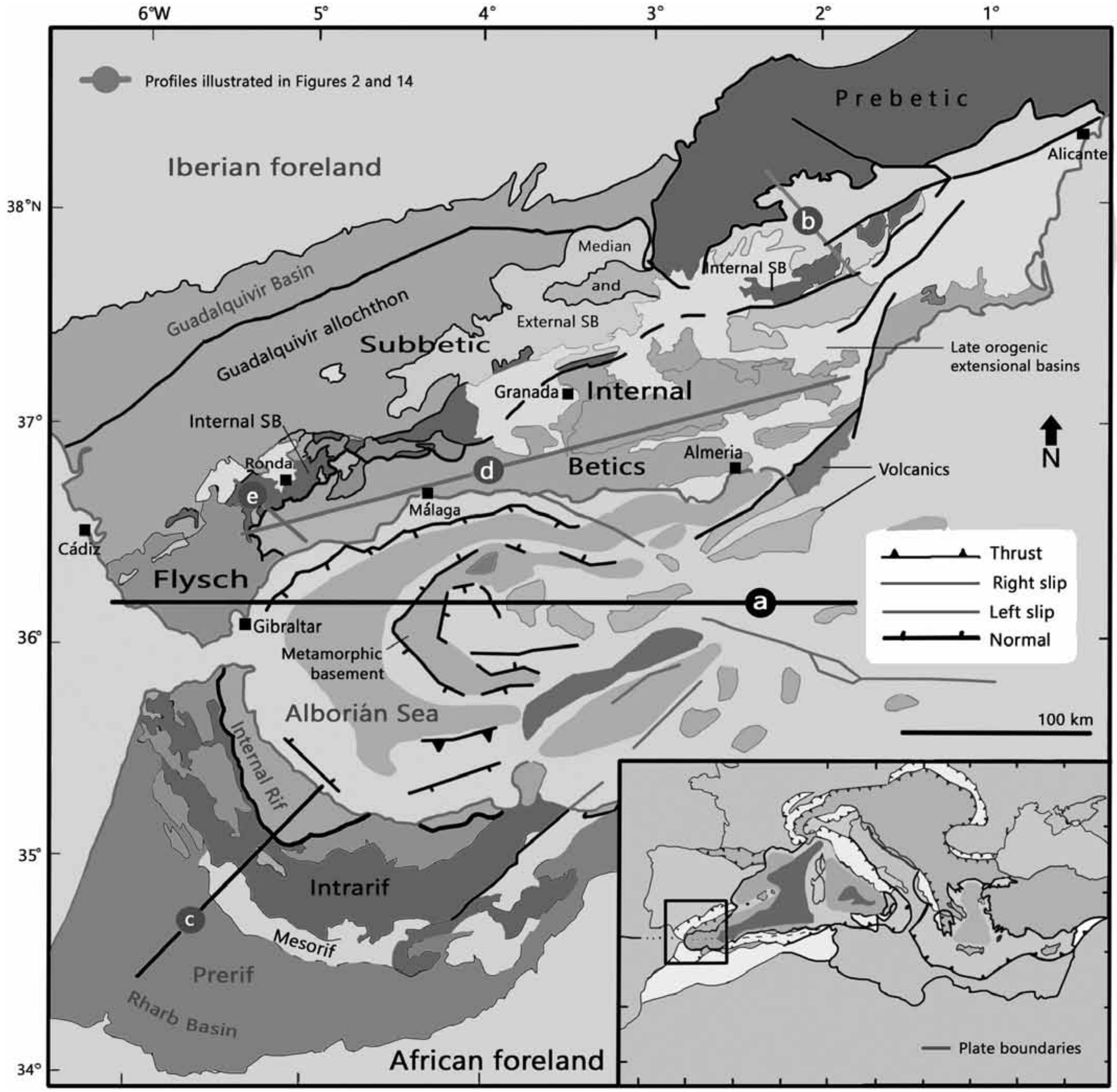

Figure 12. Tectonic map of the area showing circular metamorphic basement arc that could represent the central peak ring uplift of a large complex crater about 200 km in diameter. (Copyright 2013 from Platt et al., 2013, p. 316. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.)

If the Alboran Basin is an impact crater, the Gibraltar arc suggests a diameter of about 200 km. It would represent a large complex crater with a peak ring complex in the center (Oard, 2013b). The center of this impact likely is the raised circular area bounded by normal faults just east of the western Alboran Basin (Figure 12), so that the South and North Alboran Basin could be part of the annulus of the crater. The arcuate shape of the Alboran Basin may

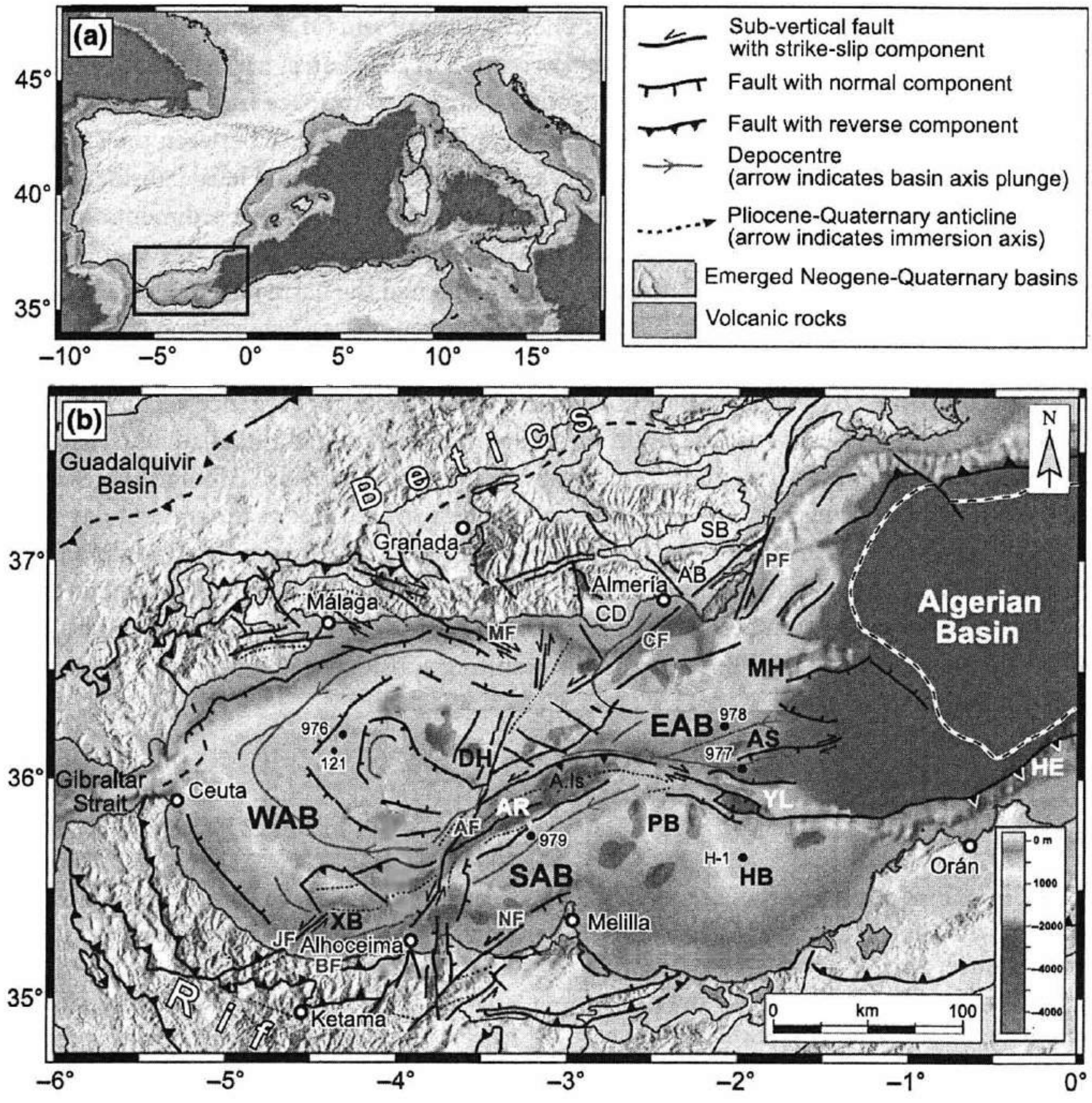

Figure 13. A larger tectonic map of the western Mediterranean Sea showing the deep Algerian Basin. (Copyright 2013 from Martinez-Garcia et al., 2013, p. 362, and modified by Mrs. Melanie Richard. Used in accordance with federal copyright [fair use doctrine] law. Usage by *CRSQ* does not imply endorsement of copyright holder.)

reflect the outer annulus of this raised peak ring complex.

In this proposed scenario, part of the internal zones should have sunk back toward the Alboran Basin, resulting in extension and low-angle normal faults seen just off shore and inland (Martinez-Garcia et al., 2013). The metamorphic rocks of the internal zone and the Alboran Sea are exhumed from the middle to lower crust and were thrust out along the edge of the Alboran Sea before sliding back toward the basin during extension, although these have alternative explanations as well. Other metamorphic rocks were uplifted in the center of the basin during crater rebound. All these events would have formed very rapidly. It appears that an impact could partially explain the anomalous structure and tectonics of this basin.

In this case, the eastern Gulf of Cadiz would be part of the western external zone, thrust westward, resulting in a thick stack of thrust sheets and contributing to the debris flows that slid down the steep continental slope. Iribarren et al (2007) believe the formation of the Gulf of Cadiz imbricate wedge was rapid. Crespo-Blanc (2008) believes the structures of the thrusts, especially the eddy-like features in the external zone and flysch, indicate *one* event. In both cases, an impact would explain these features.

The thin crust and shallow Moho at the Alboran Basin accounts for the gravity high; the surrounding mountains show low gravity. The high heat flow in the Alboran Basin is probably caused by the hot mantle near the surface. High seismic velocity in the remaining crust (Palomeras et al., 2014) may be the result of the destruction of the upper crust, leaving high-density lower crust and intrusive rocks. A low-velocity zones exists below the western Alboran Basin from 15 to 60 km (Palomeras et al., 2014), which could have been caused by fracturing of the upper mantle. Beneath it, from 60–650 km is a high velocity zone, but its association with any impact is unknown. It certainly is not a subduction zone.

Admittedly, the impact hypothesis has evidence in the form of arc-shaped overthrusting from a subsided basin with thin crust and high heat flow. Most of the features often associated with an impact, such as shocked quartz, iridium, tektites, shatter cones, rock breccia, etc. have not been identified. French and Koeberl (2010) suggest that the only positive evidence for impacts is shatter cones and planar deformation features (PDFs) in quartz or other crystals (Oard, 2013). However, they admit that these features would not be common. Recognizing shatter cones in the field is quite difficult, and PDFs would be found only near the center of impact. They would be absent in the annular zone because the impact pressures decrease rapidly from the point of impact outward:

> The extreme pressure and temperature conditions of shock metamorphism, and the resulting diagnostic shock-deformation effects, are produced only within a relatively small volume of target rock near the impact point" (French and Koeberl, 2010, p. 142).

Moreover, it is difficult to find planar deformation features in a marine environment. Thus, these criteria are way too stringent, especially considering a Genesis Flood environment. Besides, the researchers have not looked for such ephemeral features, as far as I know.

Was There Another Impact in the Algerian Sea Basin?

Contrary to the impact model, there is no thrust zone arc east of the Alboran Sea (Figure 12). However, it may have been destroyed by a later, strong impact in the Algerian Sea Basin (Figure 13). The intersection of the two impact outer zones may explain the chaotic boundary zone seen today between the Algerian and Alboran Basins. The volcanic Alboran Ridge would be a later uplift after the impact.

Several features of the Algerian Sea suggest also an impact may have occurred. Outward thrusts occur north, along the northern edge of the Balearic Promontory, and south, in northern Algeria, the Maghrebides (Maillard and Mauffret, 2013). The forcing of the eastern Betic Mountain first north and then back towards the south is also consistent with an impact east of the Algerian Basin. A positive gravity anomaly, high heat flow, and thin crust are also present in the Algerian Basin. But here again, there is no evidence of any iridium, glass beads, or shocked quartz to verify such an impact.

Late Flood Modification

After the presumed impact(s), the uplifted mountains that were overthrust outward were eroded by the Retreating Stage Flood currents forming planation surfaces and pediments (Farines et al., 2015), filled intermontane valleys and basins with over 2 km of sediments, and then eroded those valleys and basins during the Channelized or Dispersive Phase. The pediments would have formed later by channelized erosion down the intermontane valleys and basins (Oard, 2004). Undeformed sediments in the West Alboran Basin can possibly be explained by the backfilling of an impact crater by its associated debris.

Conclusion and Implications

Many features of the Alboran Sea and the surrounding mountains are poorly explained by uniformitarian theories, but may be consistent with an impact event large enough to form a central peak ring complex. Specifically, the extensional tectonic features found at a convergent boundary require an unusual explanation. The thinned crust; crustal fracturing; gravity anomaly distribution; metamorphic and mantle rocks in the interior zones; and arcuate, thrusted outward external zones can all be explained by the impact mechanism. The drawback to this explanation is the lack of impact-related artifacts in the Alboran Basin and surrounding areas.

Planation surfaces and pediments, valley and basin fill, and subsequent erosion all combine to place the timing of the impact in the early Retreating Stage of the Flood, the Abative Phase. Features inconsistent with an Alboran impact may be explained by a subsequent impact to the east, in the Algerian Sea, as well as by late Flood modification.

The broad-scale features of the area are consistent with an impact. If all these unusual tectonic and geophysical features were not caused by an impact, then the origin of these features may be difficult to explain by another Flood mechanism. If the Alboran Basin was caused by an impact, then it is possible that other arc-shaped features in the Mediterranean region were also caused by impacts.

References

Baumgardner, J.R. 2003. Catastrophic Plate Tectonics: the physics behind the Genesis Flood. In Ivey, Jr., R.L. (editor), *Proceedings of the Fifth International Conference on Creationism* (technical symposium sessions), , pp. 113–126, Creation Science Fellowship, Pittsburgh, PA.

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.

Buontempo, L., G.H.R. Bokelmann, G. Barruol, and J. Morales. 2008. Seismic anisotropy 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.

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.

Cunha, T.A., L.M. Matias, P. 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.

Doglioni, C., E. Carminati, M. Cuffaro, and D. Scrocca. 2007. Subduction kinematics and dynamic constraints. *Earth-Science Reviews* 83:125–175.

Duarte, J.C., F.M. Rosas, P. Terrinha, W.P. Schellart, D. Boutelier, M.-A. Gutscher, and A. Ribeiro. 2013. Are subduction zones invading the Atlantic? Evidence from the southwest Iberia margin. *Geology* 41(8):839–842.

Dündar, S. et al. 2011. Receiver function images of the base of the lithosphere in the Alboran Sea region. *Geophysical Journal International* 187:1,019–1,026.

Faccenna, C., C. Piromallo, A. Crespo-Blanc, L. Jolivet, and F. Rossetti. 2004. Lateral slab deformation and the origin of the western Mediterranean arcs. *Tectonics* 23:TC1012.

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.

French, B.M. and C. Koeberl, C. 2010. The convincing identification of terrestrial meteorite impact structures: what works, what doesn't, and why. *Earth-Science Reviews* 98:123–170.

Grevemeyer, I., N. Kaul, and A. Kopf. 2009. Heat flow anomalies in the Gulf of Cadiz and off Cape San Vincente, Portugal. *Marine and Petroleum Geology* 26:795–804.

Grevemeyer, I., E. Gràcia, A. Villaseñor, W. Leuchters, and A.B. Watts. 2015. Seismicity and active tectonics in the Alboran Sea, Western Mediterranean: constraints from an offshore-onshore seismological network and swath bathymetry data. *Journal of Geophysical Research* 120(B12):8,348–8,365.

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.

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.

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.

Maillard, A. and A. Mauffret. 2013. Structure and present-day compression in the offshore area between Alicante and Ibiza Island (Eastern Iberian Margin). *Tectonophysics* 591:116–130.

Mancilla, F.D., G. Both-Rea, D. Stich, J.V. Pérez-Peña, J. Morales, J.M. Azañón, R. Martin, and F. Giaconia. 2015. Slab rupture and delamination under the Betics and Rif constrained from receiver functions. *Tectonophysics* 663:225–237.

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.

Mattei, M., F. Cifelli, and N. D'Agostino. 2007. The evolution of the Calabrian Arc: evidence from paleomagnetic and GPS observations. *Earth and Planetary Science Letters* 263:259–274.

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.

Meyer C. and W.P. Schellart. 2013. Three-dimensional dynamic models of subducting plate—overriding plate—upper mantle interaction. *Journal of Geophysical Research* 118(B2):775–790.

Miller, M.S, A.A. Allam, T.W. Becker, J.F. Di Leo, and J. Wookey. 2013. Constraints on the tectonic evolution of the western most Mediterranean and northwest Africa from shear wave splitting analysis. *Earth and Planetary Science Letters* 375:234–243.

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.

Oard, M.J. 2000. Subduction unlikely—plate tectonics improbable. In Reed, J.K. (editor), *Plate Tectonics: A Different View*, pp. 93–145, Creation Research Society, Chino Valley, AZ.

Oard, M.J. 2004. Pediments formed by the Flood: evidence for the Flood/post-Flood boundary in the Late Cenozoic. *Journal of Creation* 18(2):15–27.

Oard, M.J. 2006. The uniformitarian challenge of ultrahigh-pressure minerals. *Journal of Creation* 20(1):5–6.

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

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

Oard, M.J. 2013b. What do impacts accomplish in the first hour? *Journal of Creation* 27(1):90–98.

Oard, M.J. 2013. Large catatonic basins likely of impact origin. *Journal of Creation* 27(3):118–127.

Oard, M.J. 2014. *The Flood/Post-Flood Boundary Is in the Late Cenozoic with Little Post-Flood Catastrophism*. http://michael.oards.net/PostFloodBoundary.htm.

Oard, M.J. and J.K. Reed. 2017. *How Noah's Flood Shaped Our Earth*. Creation Book Publishers, Powder Springs, GA.

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., 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.

Platt, J.P. and R.L.M. Vissers. 1989. Extensional collapse of thickened continental lithosphere: a working hypothesis for the Alboran Sea and Gibraltar arc. *Geology* 17:540–543.

Robuchon, G., F. Nimmo, J. Roberts, and M. Kirchoff. 2011. Impact basin relaxation at Iapetus. *Icarus* 214:82–90.

Ruiz-Cruz, M.D. and C.S. de Galdeano. 2013. Coesite and diamond inclusions, exsolution microstructure and chemical patterns in ultrahigh pressure garnet from Ceuta (Northern Rif, Spain). *Lithos* 177:184–206.

Searls, M.L., W.B. Banerdt, and R.J. Phillips. 2006. Utopia and Hellas basins, Mars: twins separated at birth. *Journal of Geophysical Research* 111, doi:10.1029/2005JE002666, 2006.

Stewart, S.A. 2003. How will we recognize buried impact craters in terrestrial sedimentary basins? *Geology* 31(11):929–932.

Taylor, B (editor). 1995. *Backarc Basins Tectonics and Magmatism*, Plenum Press, New York, NY.

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.

Torne, 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.

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 active tectonics of the Western Mediterranean: implications for the kinematics and dynamics of the Nubia-Eurasia plate boundary zone. *Journal of Geodynamics* 49:123–129.

Walker, T. 1994. A biblical geological model. In Walsh, R.E. (editor), *Proceedings of the Third International Conference on Creationism* (technical symposium sessions), pp. 581–592, Creation Science Fellowship, Pittsburgh, PA.

Wieczorek, M.A. and R.J. Phillips. 1999. Lunar multiring basins and the cratering process. *Icarus* 139:246–259.

Wünnemann, K. and B.A. Ivanov. 2003. Numerical modelling of the impact crater depth-diameter dependence in an acoustically fluidized target. *Planetary and Space Science* 51:831–845.