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**Commentary**

# It Is Still Viable!

## *Paleogene Gulf of Mexico Water-Level Drawdown Hypothesis*

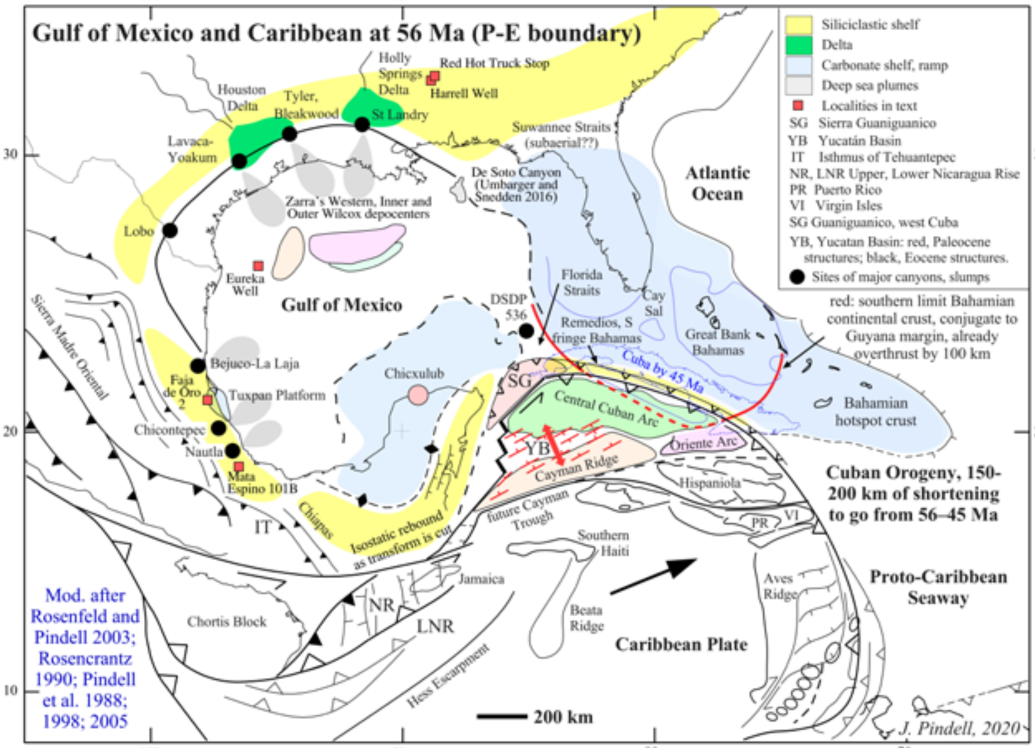


*Figure 1. Gulf of Mexico and Caribbean at the 56 Ma most likely time of drawdown, with localities cited in text. The Cuban Arc/prism had begun obduction onto the shallow-water "Remedios Belt" defining the southern edge of the Bahamas Platform, imbricated within Cuban thrust sheets by 45 Ma after 150-200 kilometers of further shortening.*

Josh Rosenfeld highlighted some perspectives on the Paleogene drawdown hypothesis in the Gulf of Mexico in the Historical Highlights column of the April 2020 issue of the EXPLORER, a result of suspected isolation from the world ocean during the Cuban arc-Bahamas collision with implications for Wilcox reservoir deposition. In contrast, John Snedden and colleagues portrayed the Wilcox as a period of normal marine deposition, requiring no such drawdown, in the May 2020 issue of the EXPLORER. Still another concept was presented by Roger Higgs at the South African 2009 AAPG International Conference and Exhibition, that marine isolation occurred but that fluvial input exceeded evaporation such that the Gulf became brackish, hence the poor development of Wilcox fauna.

We have maintained a keen interest in this hypothesis since its introduction by Rosenfeld and James Pindell in their 2003 AAPG Memoir 79 article, and have continued studying the problem since 2011 as a task in the ongoing industry-sponsored Cordilleran Mexico-Gulf of Mexico work program by research firm Tectonic Analysis Ltd. Whereas Rosenfeld called for further study, Snedden attempts to douse the theory by noting perceived problems with timing and specific issues of the original hypothesis, such as the expectation of evaporative deposition during the event. Below, we update readers on seven areas of progress and suggest it is too soon to close the door on constructive discussion of this important theory.

### Paleogene Salt in the Gulf?

The original 2003 paper noted that the Mata Espino 101B well in Veracruz Basin (figure 1), far from the Louann or Campeche salts, penetrated thick halite amidst Paleocene shales. This is why a Paleocene event as extreme as the Mediterranean Messinian drawdown was first contemplated. However, in May 2016, Steve Cossey and Mark Bitter sampled salt cores from this well for strontium isotope dating by colleague Bodo Weber at CICESE, Ensenada, Mexico, as tasks in the Cordilleran Research Program. Pindell informed a January 2019 HGS audience as well as the 2019 ACE, both in Houston, that the halite was deposited 169 million years ago (Bajocian) and an entrained gypsum clast 166 million years ago (Bathonian). Based on the structural setting, Pindell and colleagues have proposed in a chapter of the 2020 GSA Special Paper 546 that the salt migrated into the Paleocene shale from a continental basin onshore Mexico. This paper also shows that the salt in the main Louann and Campeche salt basins, and not just the salt in the U.S. interior basins, is also Bajocian. Thus, the 2003 idea that the drawdown may have caused evaporitic deposition lost basis. We now consider that if drawdown due to marine isolation occurred, then (a) some 3-4 kilometers of water always remained present in the Gulf basin assuming an original Paleocene paleo-depth in the deep Gulf of about 5 kilometers, prior to the majority of Cenozoic clastic infilling, and (b) that fluvial input was sufficient relative to evaporation to prevent episodes of severe desiccation. Thus, we do not expect evaporites or other shallow marine or subaerial facies in the deep Gulf; we do not expect evaporative signatures in Gulf oils; and we do not expect turbiditic and pelagic deposition ever to have ceased in the deep Gulf, even during possible periods of drawdown. Note, however, that the 1965 Eureka well, drilled in 2,500 feet of water east of the mouth of the Río Grande (figure 1), cored a section interpreted as red beds, sylvite and halite 200–400 feet below the presumably bathyal Upper Eocene (Anderson and Parrott, 1969). This well and perhaps others unknown to us are worth examining again in light of both the drawdown hypothesis as well as local salt diapirism which might allow for an alternative explanation of these cores.

### Paleo-Canyons Along the Western Gulf Margin

Several Paleogene paleo-canyons in Mexico have the advantage over their U.S. cousins of being exposed for field study and sampling (figure 1). Several papers by Cossey and Vásquez and colleagues in 2014, 2016 and 2019 presented a wealth of information about previously unmapped outcrops, concluding that the upper bathyal strata (200-600 meters paleo-water depth) hosting the canyons had been incised subaerially over 100,000–800,000 years of canyon development at about 56 million years ago. In the sub-surface, the Chicontepec paleo-canyon incises carbonate strata down to the Jurassic level, no doubt lithified rock during incision. Further, the relief on the canyon thalweg in a small part of the canyon is over 700 meters – half the depth of the Grand Canyon, and the width of the canyon is only 11 kilometers. We question whether so much lithified rock can be cut so quickly by submarine currents, and suspect that fluvial incision was required. Interpretations in the Cossey and Vásquez papers favouring the fluvial viewpoint include:

- Bitumen seeped subaerially onto parts of Chicontepec paleo-canyon terraces, and are overlain by paleosols. Limonite tubes below the bitumen indicate rooting just prior to the seeping of the bitumen layer. Upwards, the overlying turbidite deposits denote a rapid return to upper bathyal marine conditions.
- In Tampico-Misantla Basin, Steve Cossey and Mark Bitter interpret outcrops 100 meters stratigraphically above one of the bitumen beds as denoting karsting within upper bathyal, lowermost Eocene section, prior to Laramide (Eocene) folding (figure 2). This could evidence a second

**Jim Pindell** integrates plate tectonic data with field analyses of stratigraphy and structure to create regional evolutionary syntheses and to constrain petroleum systems. Pindell has directed industry-sponsored research programs at Dartmouth College and through Tectonic Analysis Ltd. since 1985, and has held academic research positions at Lamont Earth Observatory, Dartmouth College, University of Houston, Cardiff University (Wales), and is now an adjunct professor at Rice University. Pindell has a doctorate in geology under John Dewey from Durham, England, a master's under Kevin Burke from SUNY Albany and a bachelor's from Colgate University. Pindell's research programs and teaching have focussed on Colombia, Venezuela, Trinidad-Guianas, Barbados, the Andes system, the Atlantic and its margins, numerous Caribbean islands, Mexico, and the Gulf of Mexico. He has published about 100 papers and articles with students and colleagues on these regions, and has studied passive margin development with ION Geophysical in Houston since 2011.

**Stephen Cossey** is chief geoscientist at Cossey and Associates Inc. geoconsulting based in Durango, Colo. He has more than 40 years' experience in the petroleum industry. He worked for Conoco Uranium exploration and International Exploration from 1978 to 1983 and Sohio/BP from 1983 to 1995. He was based in Dallas with Sohio, working oil and gas exploration in frontier areas of the United States. From 1990-'92, he worked at BP Research in Sunbury, UK and helped to start BP's deepwater research program. The remainder of the time at BP was spent working exploration in the onshore United States and Gulf of Mexico. In 1995 he started his own consulting company. Since then, he has consulted for more than 150 global exploration companies and is skilled in interpreting deep-water sequences and in creating sequence stratigraphic and depositional models from core, well, and seismic data. Cossey also teaches field excursions in France, Spain and Mexico and has conducted over 20 courses in these areas.

This article and the paper published in 2019 in GeoGulf 19 Transactions contains a lot of the conclusions from fieldwork during the last 16 years in eastern Mexico with Mark Bitter, Francisco (Paco) Meneses of GYMSA (Mexico City), Juan Ampacun (Tourism Directorate of Tampico) and others.

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short-lived drawdown event.

▸ In a subsurface portion of the Chicontepec paleo-canyon, a possible plunge pool about 150 meters deep has been mapped and interpreted from 3-D seismic at the base of the steepest canyon gradient (PEMEX, 2012, personal communication). Further, in their classic 1991 Wilcox paleo-canyon paper, Bill Galloway and colleagues identified dip reversals in the thalweg of the Yoakum paleo-canyon which some workers consider might also indicate plunge pools. Hanging valleys and terraces are described within the Yoakum paleo-canyon that we consider may be uniquely fluvial features.

▸ A chronostratigraphic analysis presented by Paul Cornick and others from Petrostrat at the 2019 AAPG Annual Convention and Exhibition documented numerous unconformities within the offshore Wilcox, with an estimated 50 percent of time missing in some wells. A particularly prominent unconformity occurs immediately below the Paleocene-Eocene thermal maximum level (PETM) in many offshore wells. In the onshore upper bathyal Chicontepec Formation, the Vásquez 2014 paper portrays four basin-wide unconformities at 38, 46, 54, 60.4 million years ago, and more than half the rock record is missing. The 54 Ma unconformity could be judged 56 Ma on updated timescales.

### The Lavaca and Yoakum Paleo-Canyons

It is commonly perceived that the Lavaca "canyon" represents a mega-slump of the paleo-shelf edge at about 60 Ma, whereas the Yoakum paleo-canyon denotes deeper and more focussed channel incision at 56 Ma (figures 1, 3). The Yoakum paleo-canyon was likely formed just before the PETM because the backfilled Yoakum shale corresponds "closely with the Paleocene-Eocene boundary" (Snedden and Galloway, 2019 p. 178). Thus, the Yoakum and Chicontepec paleo-canyons correlate to the accuracy of current dating. Current knowledge of the Nautla and Bejuco-La Laja paleo-canyons (figure 1) suggests they also formed at 56 Ma.

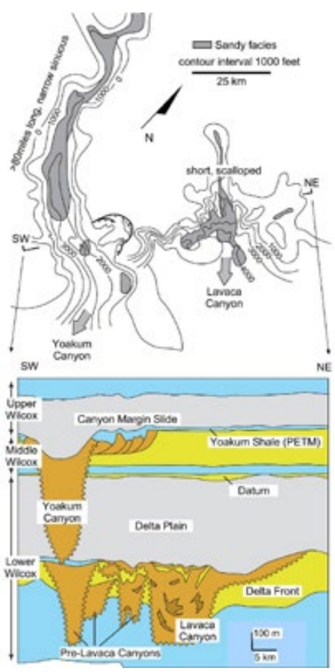


*Figure 3. Map showing original canyon paleobathymetries, and cross section of the Yoakum and Lavaca paleo-canyons in Texas. The Yoakum paleo-canyon was cut into Middle and Lower Wilcox just before the PETM (marked by Yoakum Shale). Preservation of slumps at the Canyon Margin Slide suggests slumping occurred upon Gulf refill rather than during incision. Modified after Snedden and Galloway (2019).*

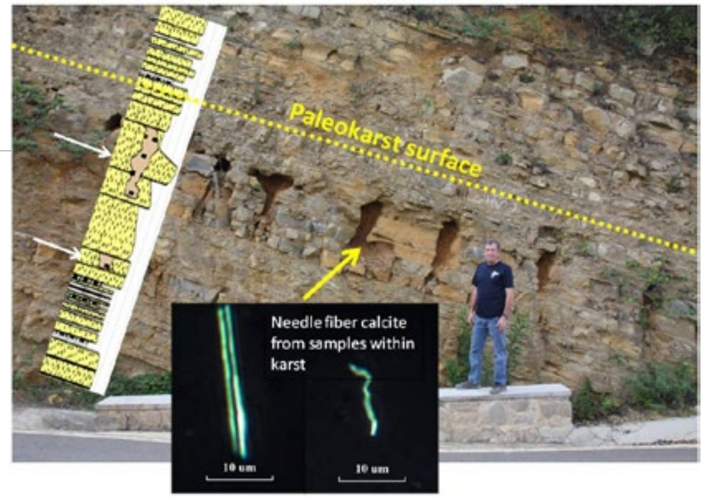


*Figure 2. Paleo-karst in the lowermost Eocene upper bathyal calcareous turbidites of Eastern Mexico, approximately 100 meters stratigraphically above the Paleocene/Eocene boundary, possibly recording another drawdown interval that may correlate with the upper cycle of Wilcox 1B of Zarra and others. White arrows point to two of the four observed karsted intervals at this outcrop. Modified from Cossey et al. (2019).*

### Magnitude of the Drawdown

A minimum magnitude of the possible drawdown just before 56 Ma is suggested by adding 200-600 meters to subaerially expose upper bathyal seafloor in Eastern Mexico, and up to 700 meters more to expose the bases of the paleo-canyons to fluvial incision, some of which cut through solid rock. Alternatively, Rosenfeld's

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1,500–2,000 meter estimate derives from the paleo-depth of karsting around Gulf margins, based on work by Andy Horbury and others with PEMEX published in the 2003 AAPG Memoir 79, who state "Direct evidence of the karstification related to major lowstands of as much as 1 kilometer or more is seen easily in the geology of the Tuxpan Platform, as well as within other platform systems and even karstic fabrics in basinal carbonates in the Southeast Basin." Horbury et al. conclude that there has been freshwater diagenesis of the El Abra reservoirs, prior to the arrival of hydrocarbons.

In addition, PEMEX biostratigraphers have reported from the Faja de Oro-2 well (figure 1) both Maastrichtian and Paleogene planktonic foraminifera as young as early Ypresian (early Eocene) in a breccia 1,200 meters below the top of the middle Cretaceous El Abra Formation. This implies karstification/infilling to at least 1,200 meters paleo-depth at about P-E boundary time, and that the entire Tuxpan Platform could have been sitting above water level for a short time, much like the foundations of Mediterranean islands during the Messinian event.

### Other Notable Locations of the 56 Ma Unconformity

Gulick and others in 2017 reported that the PETM at the continuously-cored IODP–IDP Chicxulub peak-ring (well site M0077; figure 1) is marked by a black shale, barren of fauna and about 24 centimeters thick. This overlies an unconformity and a 7.5 centimeter-thick carbonate hard ground that is burrowed and contains shallow water fauna along with reworked material from the impact. These two thin layers are sandwiched between upper bathyal sediments (300-400 paleo-water depth) below and upper to middle bathyal sediments (500–700 meters water depth) above. The fauna and impact materials are presumed to have been reworked into the deeper water. But what if they were not? The observations also accord with the expected result of a drawdown with possible subaerial exposure. Discussions with Michael Whalen acknowledge that the hardground could record subaerial exposure, with as much 1 to 3 million years of time missing at the unconformity. The unconformity is the same age as the incision at Yoakum and Chicontepec paleo-canyons. In the U.S. margin, a 2014 paper by Appy Sluijs and colleagues documents the 56 Ma unconformity beneath the PETM in the Harrell well and at the Red Hot Truck Stop outcrop (figure 1), where 100,000 to 500,000 years of record is believed missing.

### Did the Suwannee Strait Provide a Second Gateway to the Atlantic?

The Suwannee Strait (figure 1) is generally thought to have remained connected to the Atlantic through the Paleogene, such that the continuity of the speculated Yucatán-Cuba-Florida barrier is moot. This may be true for most of the time, but we are not convinced that a pre-Ypresian (early Eocene) unconformity does not exist. A karsted erosional surface of this approximate age is apparent in northern onshore Florida on several seismic lines observed by us in ION reprocessed data. Further, we cannot help questioning the accuracy of dating at the base of the "Carbonate Slope Deposit," cited in the 2016 article by Umbarger and Snedden from wells in the De Soto paleo-canyon as 63 Ma; the Cossey and others' paper last year showed that faunal reworking at Chicontepec hindered a correct understanding of those paleo-canyons in outcrop for decades. Could the De Soto paleo-canyon have been cut at 56 Ma? We agree with Rosenfeld that the question of the Suwannee Atlantic connection needs more work.

### Feasibility that the Cuba-Bahamas Collision Isolated the Gulf from the World Ocean

The Snedden article suggested that the Cuban Arc was too far from the Bahamas to achieve Gulf isolation by the appropriate time, based on the UTIG Plates Project rendition of the Pindell and Kennan 2009 model for Caribbean evolution. We wish to amend this misperception by noting that 1) it is now the 56 Ma unconformity of greatest concern, rather than the 61 Ma Wilcox 4, so Cuba was at least 100 kilometers farther north, and 2) the shallow Bahamas Banks and their crustal foundation extended some 150-200 kilometers farther south and now underlie Cuba, hence the inclusion of platformal Mesozoic strata in the thrust belt (figure 1). As suggested by Pindell in his 1985 Tectonics article on the Gulf of Mexico, the Sierra de Guaniguanico Mesozoic sections were displaced from the eastern Yucatán margin by the Cuban Arc during oblique collision. This accretionary snow-plowing potentially formed a subaerial Yucatán–Guaniguanico–Cuban Arc connection during collision in western Cuba from 57 to 49 Ma as dated by overthrust flysch sections, according to a paper by our colleagues Tim Bralower and Manuel Iturralde in 1997. Less certain is whether the Central Cuban forearc and prism overthrusting the Remedios Belt rim of the southern Bahamas had achieved subaerial connection with the Great Bahamas Bank and Florida. Figure 1 portrays a feasible reconstruction for 56 Ma.

### Discussion

From the above, a Gulf-wide unconformity with missing time occurs in shelf and bathyal sections of the offshore and dates to 56 Ma, just before the PETM (55.8 Ma). This unconformity is coeval with paleo-canyon incision within bathyal section and into lithified rock. Incision in the Chicontepec, at least, appears to have been subaerial. The carbonate hardground with shallow water fauna and missing time at the Chicxulub impact ring also correlates, as does, perhaps more crudely, the deep karsting of the Mexican Tuxpan Platform. The amount of time represented by this unconformity is likely several hundred thousand years. The subsequent transgressive burial of this unconformity and paleo-canyon backfill defines the PETM in all noted sections. The potential magnitude of this water level drop far exceeds any possible eustatic fall, especially in the early Paleogene when continental glaciation probably did not exist as a driver of eustatic cyclicity, as put forth by the papers in the SEPM Special Paper 58 edited by Pindell and Charles Drake in 1998.

The Snedden article emphasised that Wilcox deposition accords with normal marine conditions. We point out, however, that the timespan of the hypothesized drawdown need only have been about 5 percent of the overall approximately 11 million years of Wilcox time, and that the evidence points to a drawdown that left 3-4 kilometers of water in the Gulf. Thus, we too would expect normal marine conditions

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to prevail in the deep Gulf throughout Wilcox time, and for the great majority of Wilcox time around the neritic and upper to middle bathyal rims.

As alternative explanations for our observations, we have contemplated tectonic mechanisms including: flexural uplift ahead of the Sierra Madre thrusting; thermal uplift of the Sierra Madre foreland due to arc magmatism; dynamic uplift associated with suspected Laramide slab flattening; structural inversion along the offshore East Mexico Transform; and isostatic unloading of the proximal margin by downslope slumping of the offshore section. However, none of these can explain both the short period and large magnitude of the observations.

Given Larry Zarra's and Charles Winker's 2007 improvements to dating the Wilcox sub-units, presented at the GCSSEPM meeting in Houston, we have long abandoned the originally contemplated link between incision of the Chicontepec and Yoakum paleo-canyons with the deposition of the older Wilcox 4 interval. The Wilcox 4 likely pertains, instead, to deflection of large Cordilleran rivers from Hudson's Bay to the Gulf, as determined by Fred Ziegler's U. Chicago Paleogeographic Atlas Project 35 years ago and greatly clarified by Bill Galloway and Mike Blum, among others. However, this does not mean that Gulf drawdown did not cause the canyon incision dated to just before the PETM (about 56 Ma). To the contrary: the observations noted herein, and lack of further paleo-canyon formation around the Gulf until the Pleistocene glacial drawdown, rather strongly suggest that a larger-than-eustatic drop in water level at 56 Ma remains an entirely viable hypothesis worthy of continued study. Likewise, why can't a rapid return of the Gulf to eustatic levels be a valid hypothesis for the 55.8 Ma drowning of all the sites mentioned herein and associated with the PETM? As Walter Pitman and many others have emphasized, transgression often removes the stratigraphic record immediately beneath the transgressive surface, so perhaps a subaerial or shallow water "record" at these sites is often denoted only by missing time.

The proposal of a drawdown far larger than a eustatic fluctuation but not severe enough to produce evaporites at 56 Ma should have implications for the deep Gulf, the sequence architecture of which is perhaps best summarized by Larry Zarra and others' 2019 Search and Discovery article. Although these authors saw no direct evidence for drawdown, we judge that the downdip correlative sequence of the 56 Ma unconformity in their designation is the lower of two cycles in their Wilcox 1B. Zarra and others report:

- The base of the lower 1B cycle is estimated at 56.7 Ma and the top is at 55.8, or the PETM.
- The Wilcox 1 (of four) sequence comprises half the total Wilcox volume in the Western Wilcox Trend, and a quarter to a third of the Inner and Outer Wilcox trends (figure 1).
- Wilcox 1B accounts for 90 percent of Wilcox 1 volume in the Western Trend, and 85 percent of Wilcox 1 volume in the Inner and Outer trends.

Thus, the Wilcox 1B, lasting only 900,000 years, comprises about 45 percent and 25 percent of the volume in all four Wilcox intervals in the Western and Inner/Outer trends, respectively. Unfortunately, Zarra does not give the relative proportions of the lower versus upper Wilcox 1B cycles. Nevertheless, the amount of clastic material that entered the Gulf at 56 Ma is striking. In addition, the karsting and possible second drawdown shown in figure 2 may be shown to correlate, after further work, with the upper cycle of Wilcox 1B (55.8-54.1 Ma); hence, drawdown on the order of 1-2 kilometers seems to us a plausible trigger for the rapid deposition of both Wilcox 1B cycles.

No one can say if Rosenfeld's idea of drawdown and subaerial exposure of the vast upper margins around the Gulf might have triggered the PETM by rapid pressure release of hydrocarbon gases and liquids (melting of clathrates). Neither do we know the exact duration of possible subaerial exposure prior to PETM flooding, but in terms of timing it appears we can say that one could have led immediately to the other.

With questions as large as those raised here, along with the entirely different questions raised by Higgs, we are unable to discard Rosenfeld's isolation/drawdown hypothesis as Snedden and colleagues have. Further, the idea that a drawdown triggered the PETM during which the Gulf was re-flooded is intriguing, but only time will tell if this will be considered as more than coincidence. If so, the numerous thermal oscillations that continued into the early Eocene as summarized by Westerhold and others in 2018 might suggest that intermittent marine isolation at the Bahamas persisted longer than considered here. E