Salt deposits in the Caribbean area

Keith H. James, Ph.D.
Consultant Geologist
16 Maeshenllan
Llandre, Bow Street, Ceredigion SY24 5DD, Wales, UK
frayiago@gmail.com

Abstract
Many data indicate presence of salt in the Caribbean area. This article summarizes information from the plate margins and interior, including stratigraphy, salt occurrences and seismic idata. While most interpretations of data are premised upon an oceanic (Pacific) origin of the Caribbean Plate, an important implication of this paper is that the Caribbean formed in place between N and S America and shares history with the Gulf of Mexico and the Yucatán basins. A valuable investigation of Caribbean salt would employ satellite data to search for oil slicks. Focus should start on the Honduran shelf, the eastern flank of the Beata Ridge, the Muertos Trough and the Aves Ridge. Reprocessing of old seismic data would be valuable.

Key Words: salt occurrences, seismic data, geologic history of the Caribbean, suggested investigations.

The article "Breaking geological paradigms with reprocessed seismic data in the onshore Colombia" work by Karyna Rodriguez in the August 2003 edition of the AAPG Explorer has important implications for Caribbean geology.

Rodriguez and others (Searcher Seismic) suggested that much higher than expected velocities of interpreted mud diapirs in Colombia's NW Sinu Basin could instead indicate salt.

Related to this, salt domes and saline springs show widespread distribution (400 x 150 km) of salt in Colombia's nearby Bogota Basin (McLaughlin, 1972). Cretaceous strata include four evaporite zones, ranging in age from Berriasian-Valanginian, through Barremian to Aptian to Turonian-Coniacian.

Three salt mines are excavated in an anticlinal trend that extends 130 km. In the Zipaquirá mine one may visit a large underground cathedral. Mud diapirs were interpreted on the eastern side of the Magdalena delta by Shepard (1973). His map shows a roughly NE trend of diapirs. Some are up to 10 km in diameter and some are surrounded by rim synclines – classic features of salt diapirs.

Higgs (2009) proposed that major salt deposits (ca. 3 km thick) were originally present to the east in neighbouring Venezuela and Trinidad. Now hidden or disappeared they could have been associated with thick (>2 kms) Upper Jurassic – Lower Cretaceous Couva Marine anhydrite deposits in the Gulf of Paria.

Flinch (2024) reported that diapirs in the Guarapiche area of northern Venezuela, close to the Gulf of Paria, contain salt that could represent a subthrust unit extending into the deeper part of the Gulf.

An oil company interpreted salt diapirs on seismic data, rooted in Jurassic salt in the SW part of the Gulf of Venezuela. Mud diapirs interpreted on seismic in the northeastern Maracaibo Basin could be salt diapirs.

Mud diapirs are also interpreted, again on old seismic data, in the major offshore Panama and South Caribbean Deformed belts. None has been drilled. They could be part of regional Caribbean salt deposits recorded by seismic data (below). The belts are separated from the mainland by wide, undisturbed basins and might ride upon salt décollements.

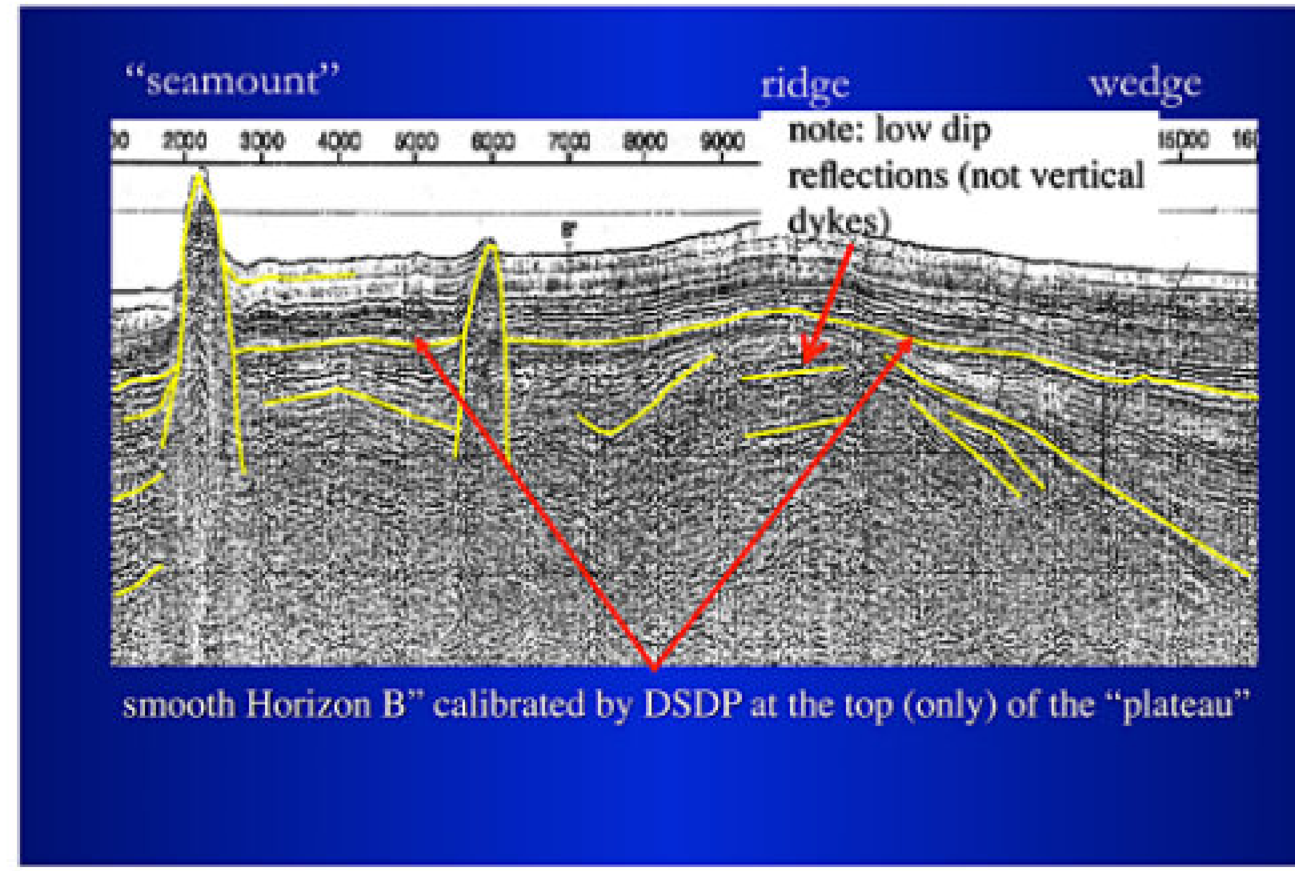

Figure 1 displays part of seismic line ew9501 recorded in the Caribbean by Lamont-Doherty Earth Observatory in 1995 and reprocessed by the University of Texas Geophysical Institute (Fig. 5). The Deep Sea Drilling Program calibrated regional seismic Horizon B" as Coniacian – Santonian - Campanian basalt. It was taken to be the top of a "Caribbean igneous plateau" (Donnelly, 1973; Kerr & Tarney 2005). Two active features rise through and push up the seafloor. The larger is called Kathy's Seamount. Horizon B" is smooth or rough. Diebold (2009) wrote that smooth B" is reminiscent of continental flood basalts. Rough B" perhaps is subaqueous (Figure 7).

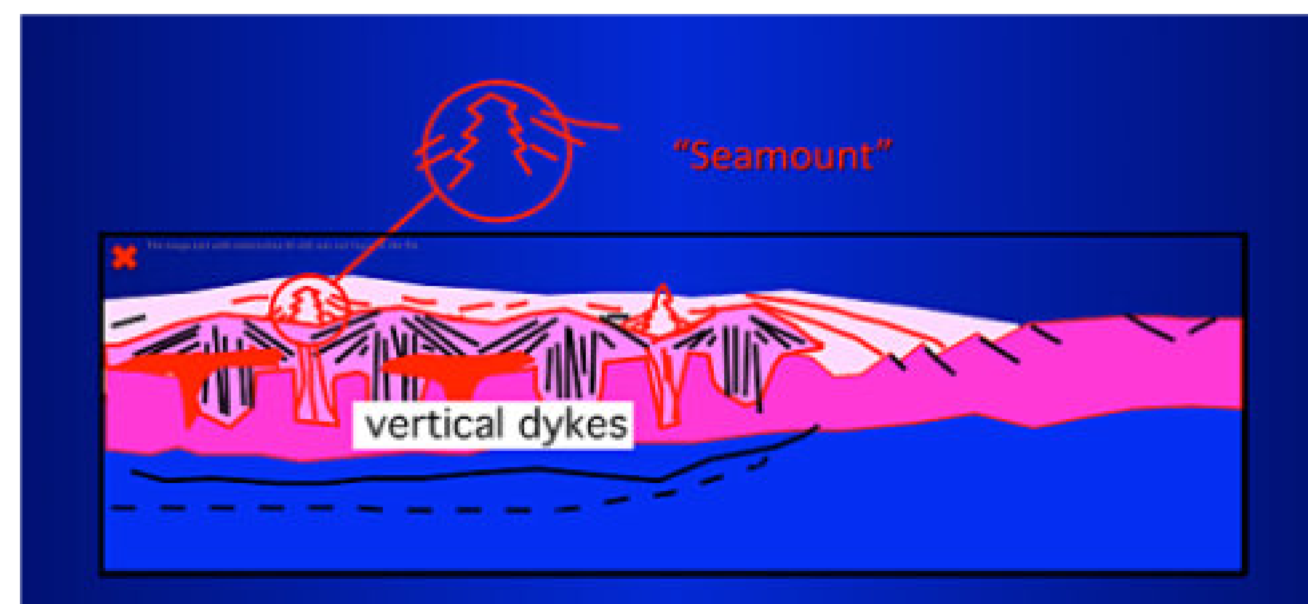

Figure 2. The Lamont published interpretation was premised on the understanding that the Caribbean contains a Large Igneous Province (LIP; Diebold, 2009), formed in the Pacific.

The interpretation shows highs of vertical dikes flanked by volcanic aprons, overlain by seamounts and further aprons. However, there is no reported volcanic activity in the Caribbean interior. The features do not show seamount geometry of build up on the seafloor. No alternative was discussed.

John Diebold, Marine Science Coordinator of Lamont-Doherty (personal communication, 2010) said that a retired colleague, T.W. (Nick) Donnelly, had been compiling a map of Caribbean seamounts. These data were missing. However, Diebold recalled that the features were common - "there are dozens, if not hundreds" - in the Colombian and Venezuelan basins. Some were buried, some protruded above the sea floor. Many were surrounded by a submerged moat (*read withdrawal/rim syncline)*. When I suggested salt diapirs as alternatives to seamounts, he said he was not familiar with salt. We were to continue our discussions of the seismic data but sadly he died.

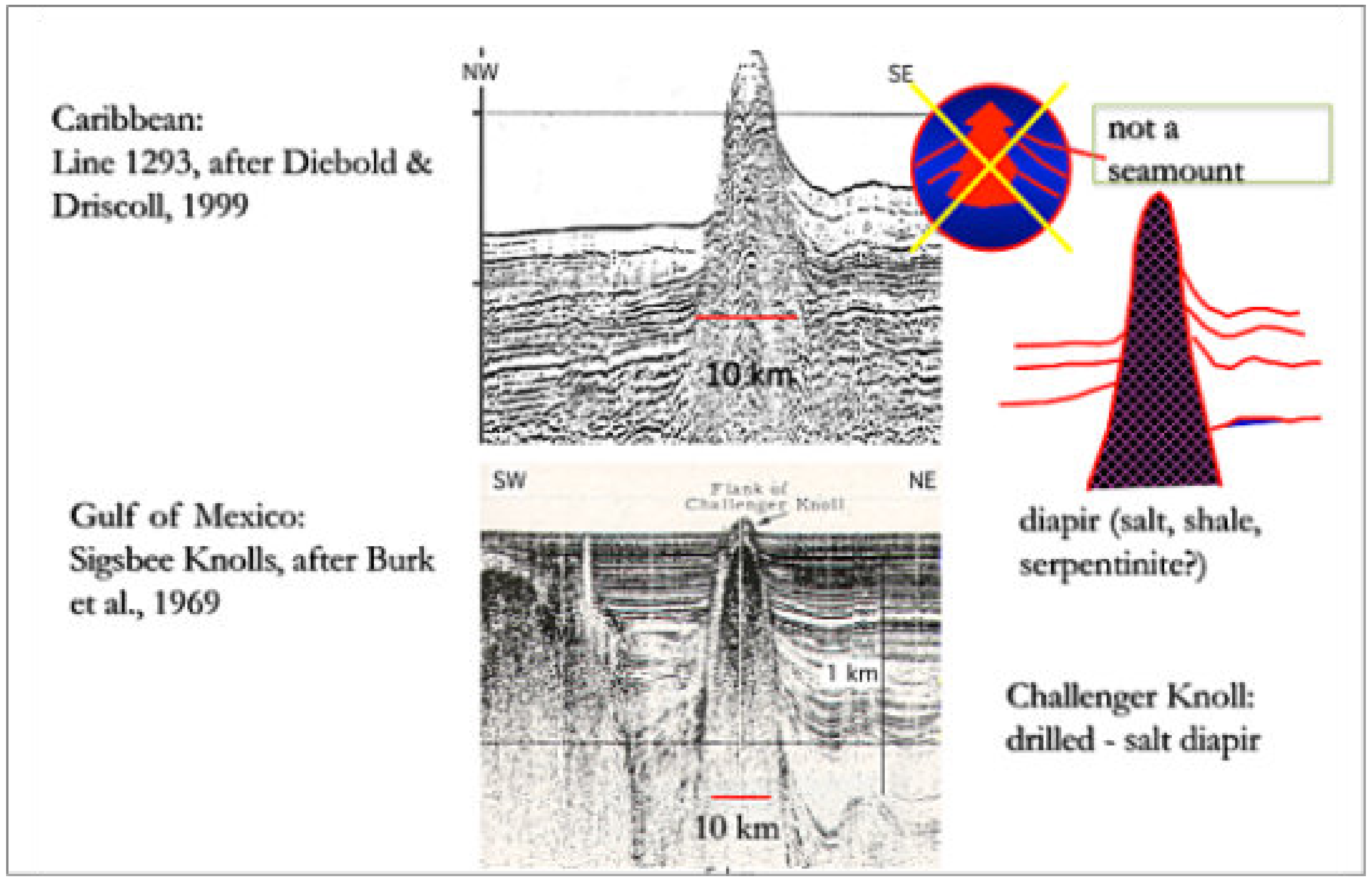

Figure 3 shows detail over the larger diapir of Figure 1 along with the cored (oil saturated sandstone recovered) Challenger salt dome of Gulf of Mexico Sigsbee Knolls, which rise 600 - 700 metres above the seafloor. These figures involve considerable vertical exaggeration – the domes are actually low amplitude mounds (Fig. 8 includes a true scale illustration). For those who worry that salt diapirs rising above the sea floor would dissolve, relax, they are protected by cap rock where insoluble content is concentrated.

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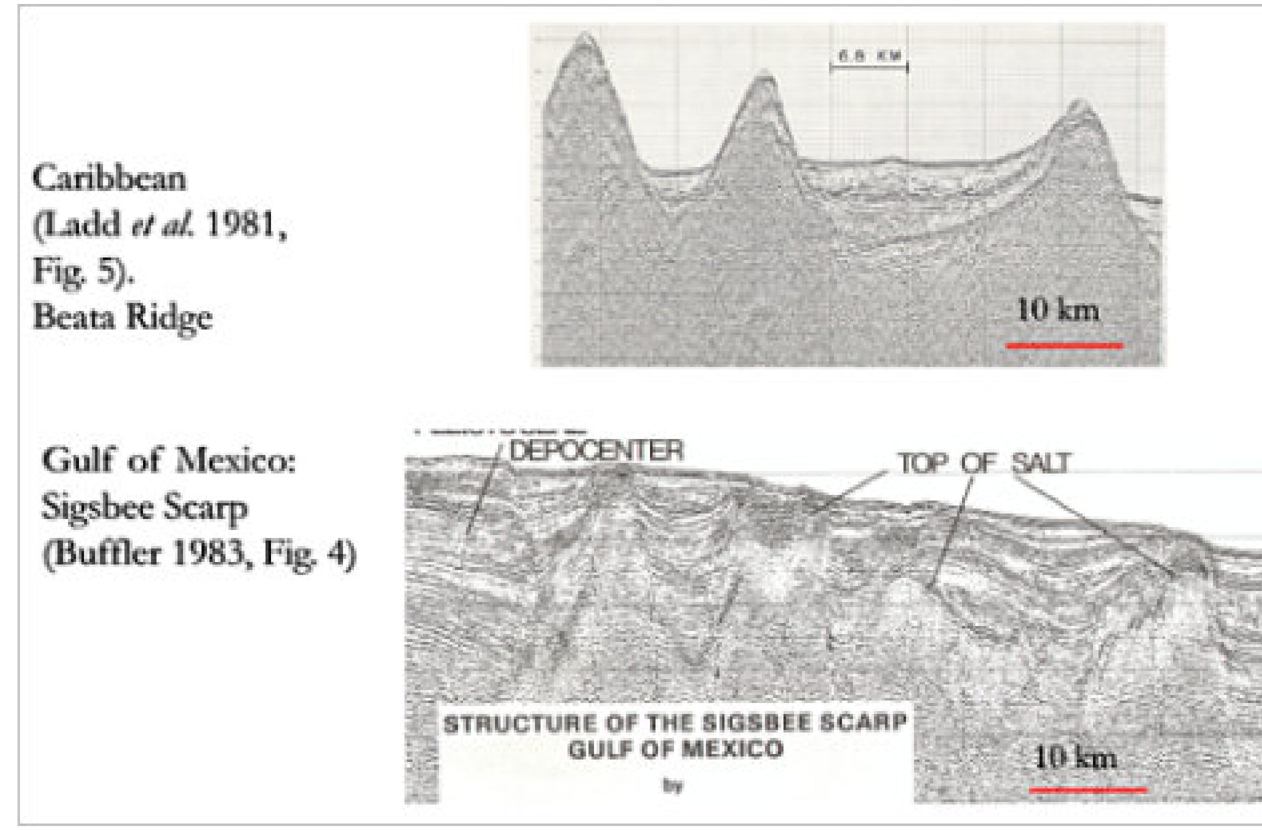

Figure 4 shows further comparison of Caribbean and Gulf of Mexico diapirs. The Caribbean illustration comes from the eastern flank of the Beata Ridge (ridges on Figure 10).

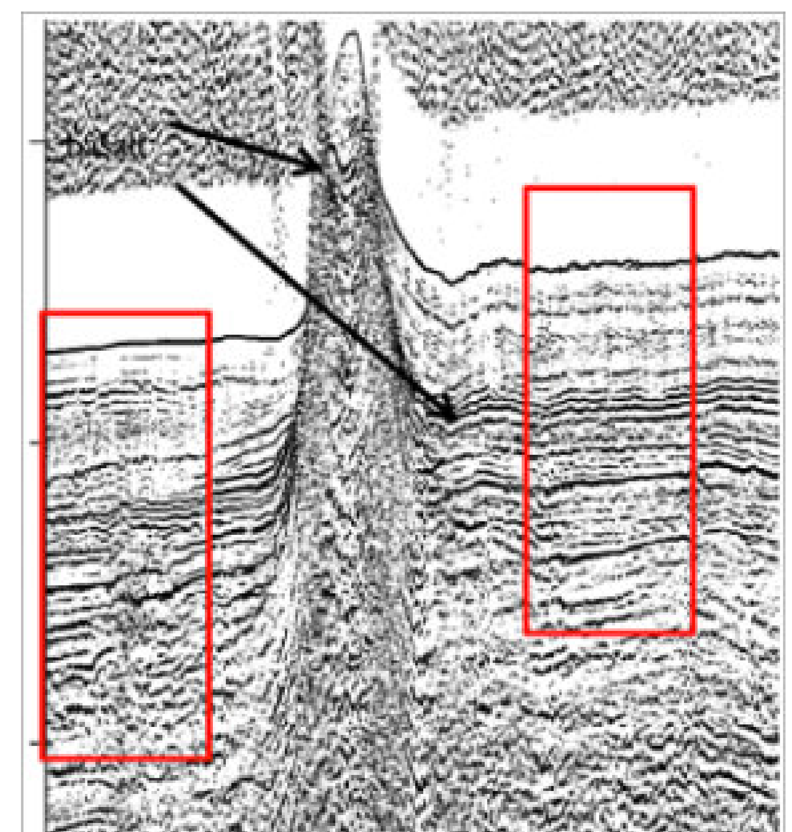

Figure 5 shows that the large, active diapir on Figure 1 is associated with a normal fault with around 150 m of throw.

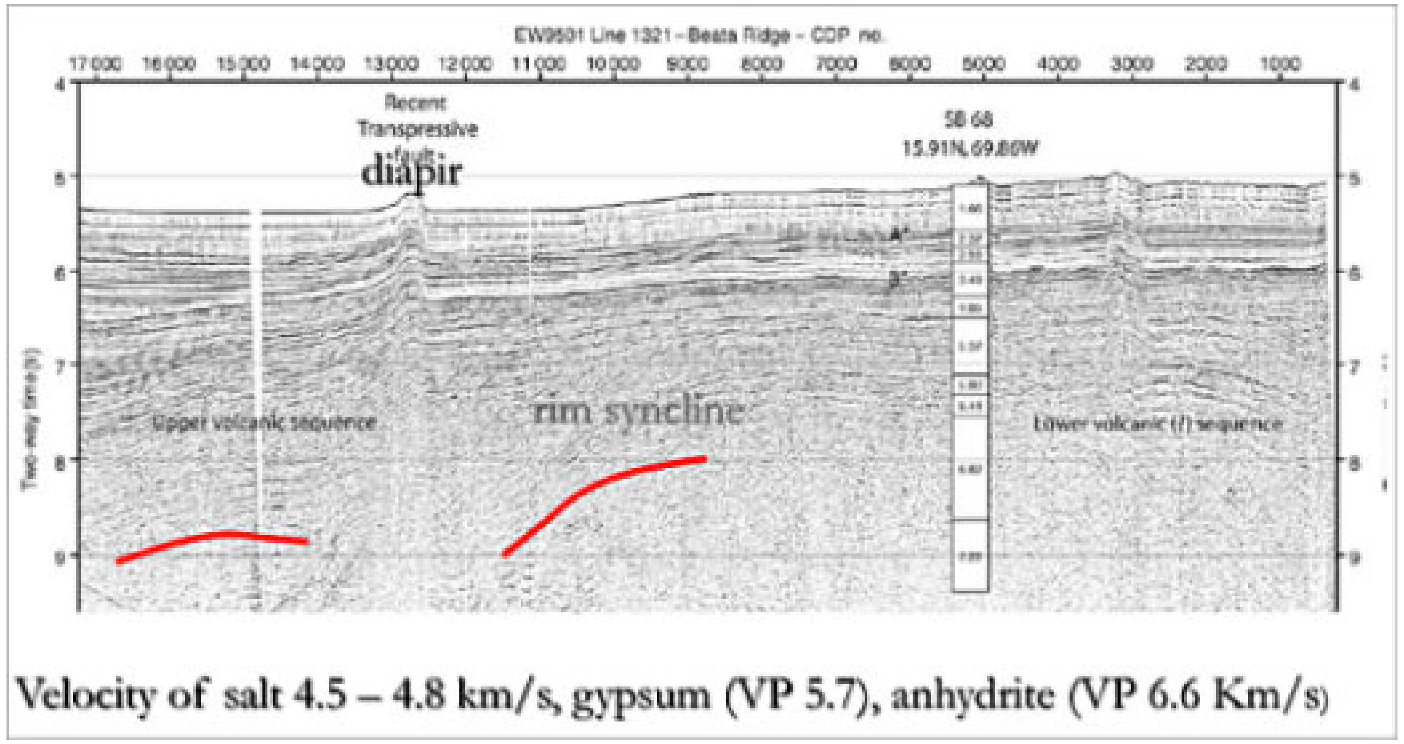

Figure 6. Seismic and sonobuoy data over the Venezuela Basin (line ew9501/1321, Diebold, 1999; Diebold et al., 1999) show lower and upper sequences, around 3.45 and 9.35 km thick below Horizon B". The lower sequence is homogeneous to reflection data but is layered and of high velocity on refraction data. There are local highs and ridges, flanked by wedges of dipping reflections. The upper sequence shows widespread reflections filling lows in the lower sequence. The lower sequence has a strong, low frequency reflection top and indications of Moho at the base.

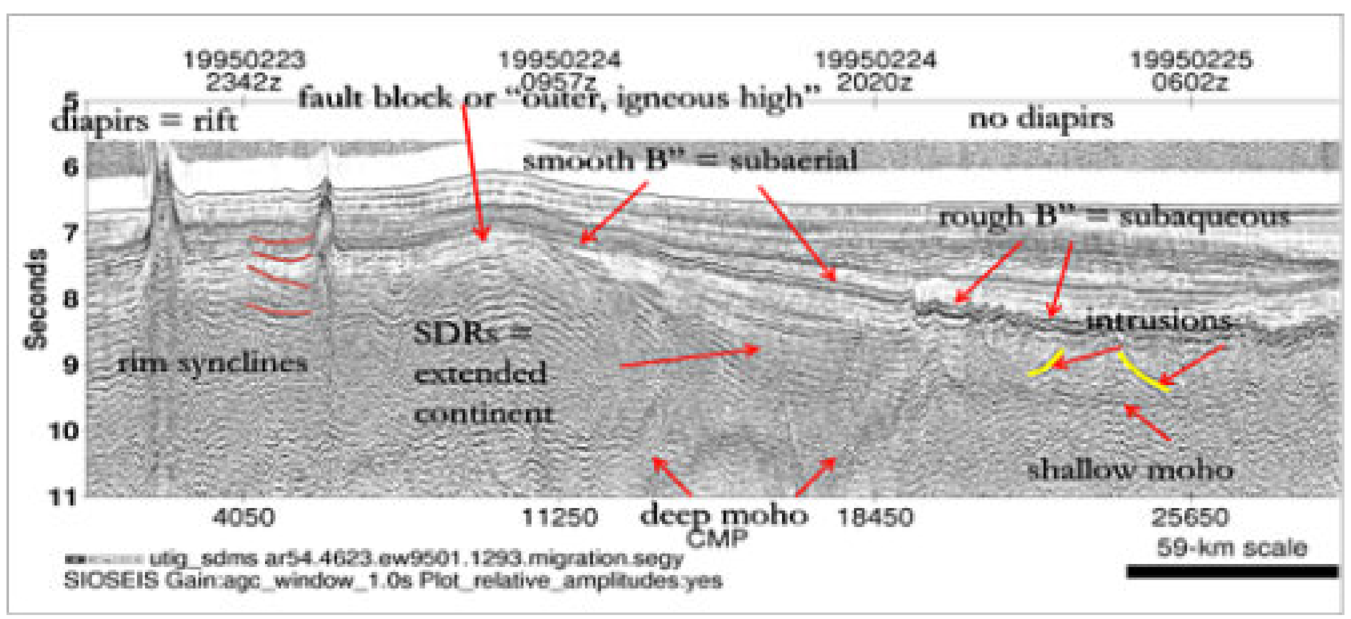

Figure 7 shows my interpretation of Line 1293 (Fig 1). The Caribbean diapir pushes through Seismic Horizon B". About 10 km wide (a common dimension of salt diapirs) and rising at least 700 m above the sea floor, it is associated with a fault (Fig. 5). Horizon B" appears near the top of the diapir (salt diapirs commonly raise large xenolths (see Figures 8, 9). Horizon B" deepens and becomes rough (subaqueous?) and the Moho rises (plate extension.

Diebold (1999) interpreted a " transpressive fault" at CDP 13000 -13500. There is a strong set of dipping horizons to the SE. I think these record withdrawal synclines descending to at least 8s twt adjacent to a vertical diapir that pushes up horizons A and B" and raises the seafloor.

Figure 8. Poza de la Sal, Spain. The largest diapir in Europe. Large xenolith of andesite above salt.

The sub-B" section shows classic extensional features. From left to right lie a platform, carrying diapirs and an outer high, a wedge of dipping reflections, both with smooth Horizon B" (subaerial? continental?) and deep Moho, then a zone of rough B" (subaqueous?) and shallow Moho.

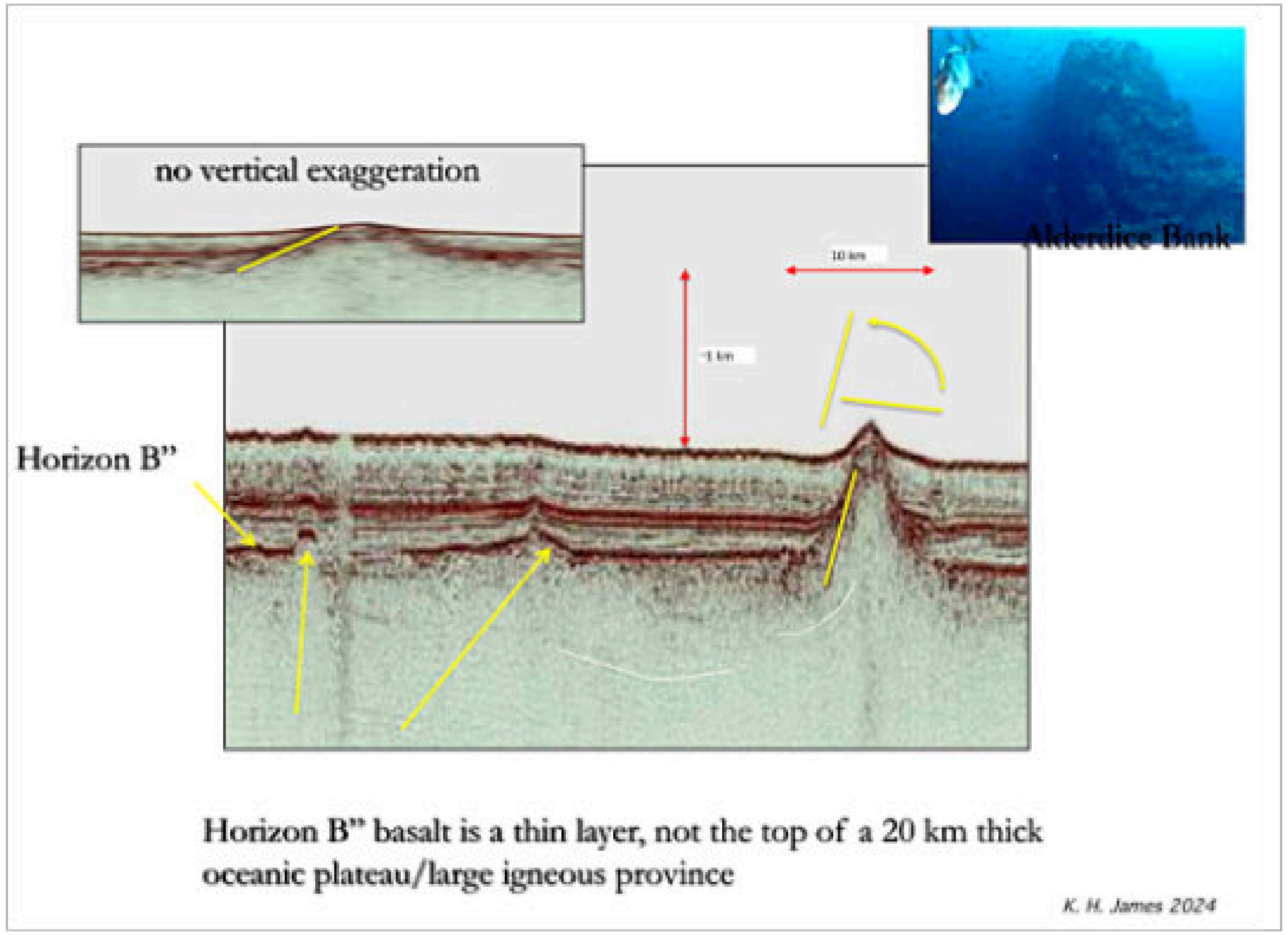

Figure 9, after Escalona & Mann (2003) shows Caribbean diapirs lifting and rotating Horizon B” (the inset shows Alderdice Bank, a Gulf of Mexico analogue offshore Louisiana, where Cretaceous basalt is raised to the seafloor (Reed, 1994). The popular concept of a Pacific-derived oceanic plateau, where B” is the top of a volcanic pile up to 20 km thick (the “Caribbean Large Igneous Province”) clearly is wrong.

The diapirs on Figure 7 arise from the pre-Turonian section. They likely are Jurassic or Neocomian salt, sharing history with the Gulf of Mexico.

Figures in Diebold 1999 show deep withdrawal synclines adjacent to diapirs. Dipping reflections descend to at least 9 seconds two-way time. If my interpretation (Fig. 7) is right, the Caribbean shares geological history with eastern N America and the major Gulf of Mexico and northern S America hydrocarbon provinces. A Triassic – upper Cretaceous section, including salt and related source rocks, is present and the Caribbean carries abundant hydrocarbon plays.

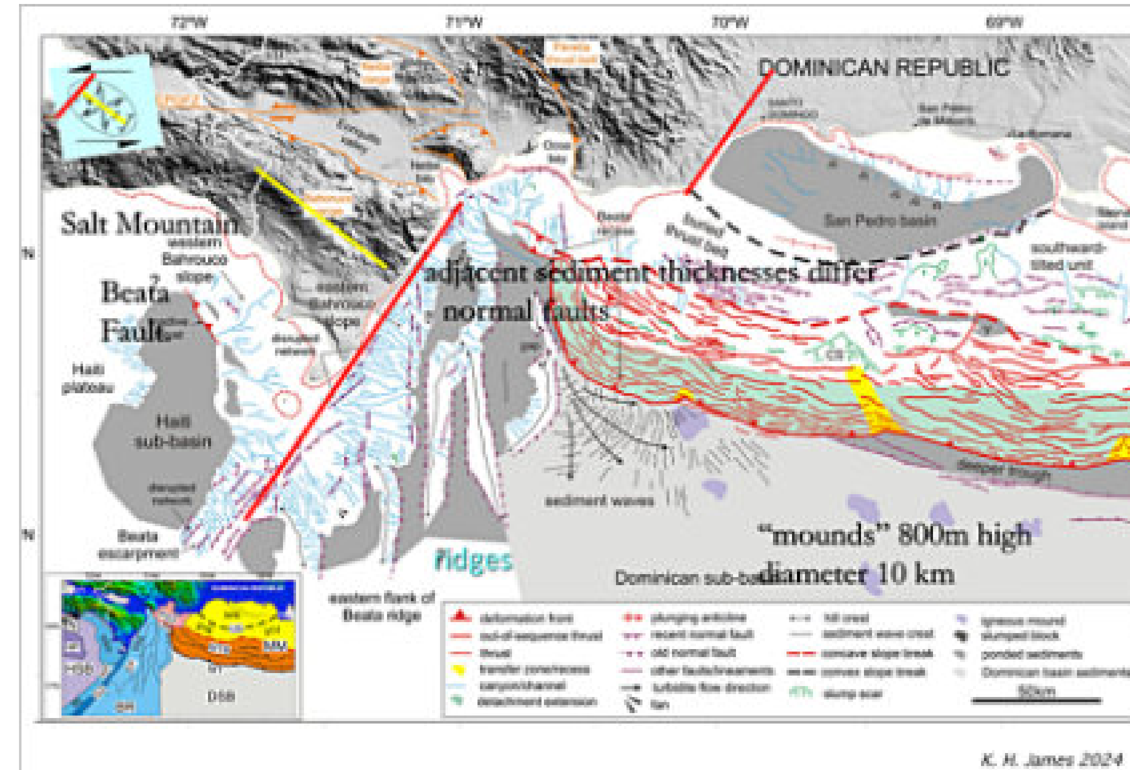

Figure 10. Map of the Domincan Sub-Basin, south of Hispaniola (after Granja-Bruña et al., 2014, Fig.4).

The 150 km NE – SW Beata Ridge, with 20+ km thick crust and low gravity/negative magnetic anomalies, separates the Caribbean Colombian and Venezuelan basins. French submersible Nautilus sampling of the western flank of the ridge (Mauffret. *et al*. 2001, Fig. 5) recovered material showing stratigraphic repetition indicative of thrusting (Miocene overlain by Palaeocene, then Lower Cretaceous,; Oligo-Miocene overlain by Palaeocene-Eocene). Perhaps the Ridge is an inverted graben.

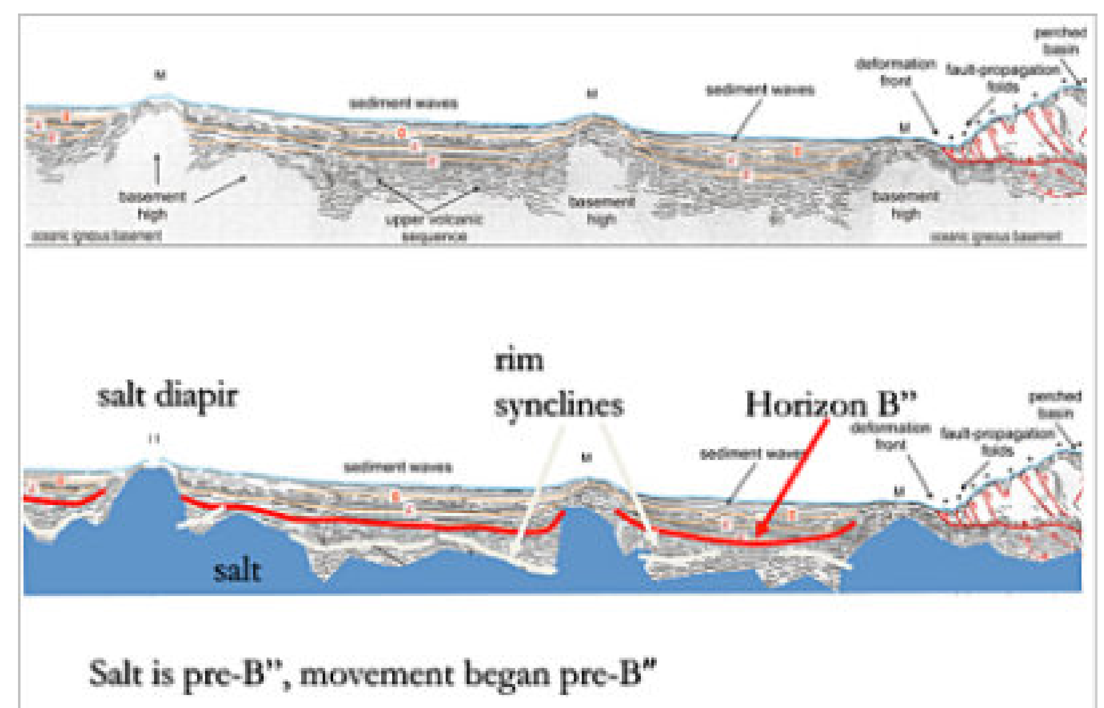

Figure 11. Seismic data over the Dominican Sub-Basin (Figure 10) (Granja-Bruña et al., 2014, Fig.5). The upper section shows interpreted basement. The lower section shows my interpretation of salt features.

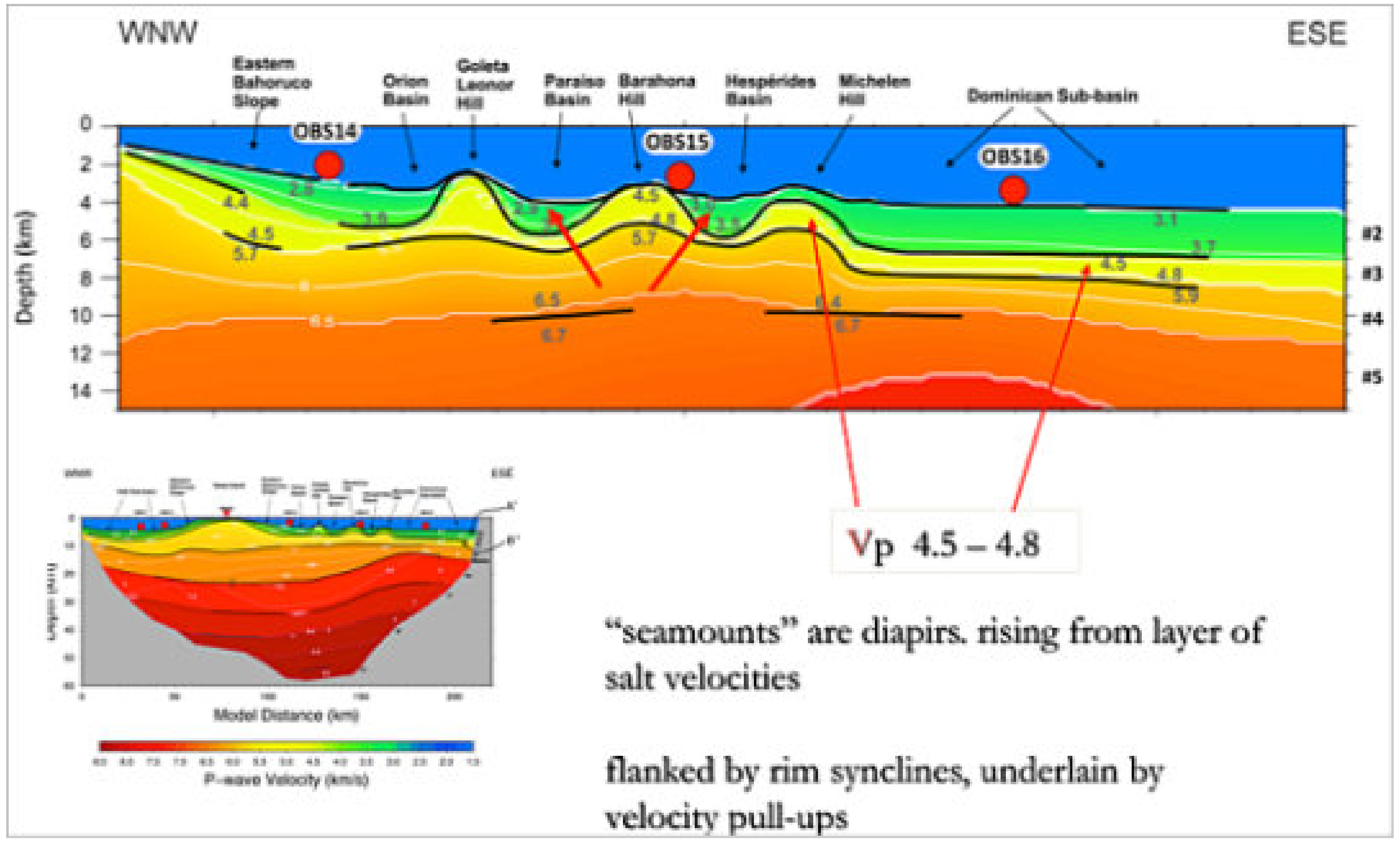

Figure 12 Eastern Beata Ridge (Nuñez et al., 2016. Figs 5, 10**).**

The eastern flank carries seafloor "hills" (ridges, basement highs, Figures 10, 11). Fault blocks for some but interpreted as seamounts by Nuñez et al, (2016). The highs, with diameters of 12 – 14 km and heights of 2.3 – 2.9 km, are flanked by withdrawal synclines and underlain by velocity pull-ups that affect Horizon B". The same features (Fig. 4) shown by Ladd et al. (1981) carry uplifted Horizon B" (see also Rezak et al, 1972, below). The question here is how does salt exist above Horizon B"? Perhaps it is allochthonous. Is it related to the onshore Hispaniola Salt Mountain (below)?

The source layer velocities (Vp 4.5 - 4.8 km/s; Nuñez, Figs. 5, 10) are typical of salt (e.g., Gulf of Mexico salt Vp 4.42 - 4.58 km/s; (Zong et al., 2015).). A section over the Aves Ridge (AR, Figure 13; Fox & Heezen 1975, p. 435 fig. 10) shows a layer of 4.2 – 4.8 km/s. In the Venezuela and Colombia basins a layer with velocity range of 3.2 - 5.5 km/s occurs between unconsolidated sediments and a 6.1 km/s crustal layer.

Almost all salt bodies contain gypsum (VP 5700 ms−1) or anhydrite (VP 6500 ms−1). Some contain K-Mg-rich salts with velocities as low as 3500 ms (Jones & Davison, 2014). Anhydrite occurs in salt dome cap rocks. Such velocities might explain the varied sonobuoy results (Fig. 6) shown in Diebold´s 2009 paper.

The Caribbean LIP is said to be uplifted onshore where the Beata Ridge meets Hispaniola (Fig. 10). Here a 16 km long diapir crops out - Salt Mountain. There are layers of gypsum, salt and argillaceous slate. This is correlated with Pliocene evaporites in the adjacent basin (Paul Mann, pers. comm., 2008).

To the east, along strike in the Muertos Trench, south of Hispaniola, "mounds", 10 km in diameter, rise 800 m above the sea floor (Figs. 10, 11). Several "volcano-like" structures are reported in the Puerto Rico Basin further east (Figure 13) (Mauffret & Leroy, 1987) and on the Lower Nicaragua Rise SW of the Beata Ridge (Case et al., 1990).

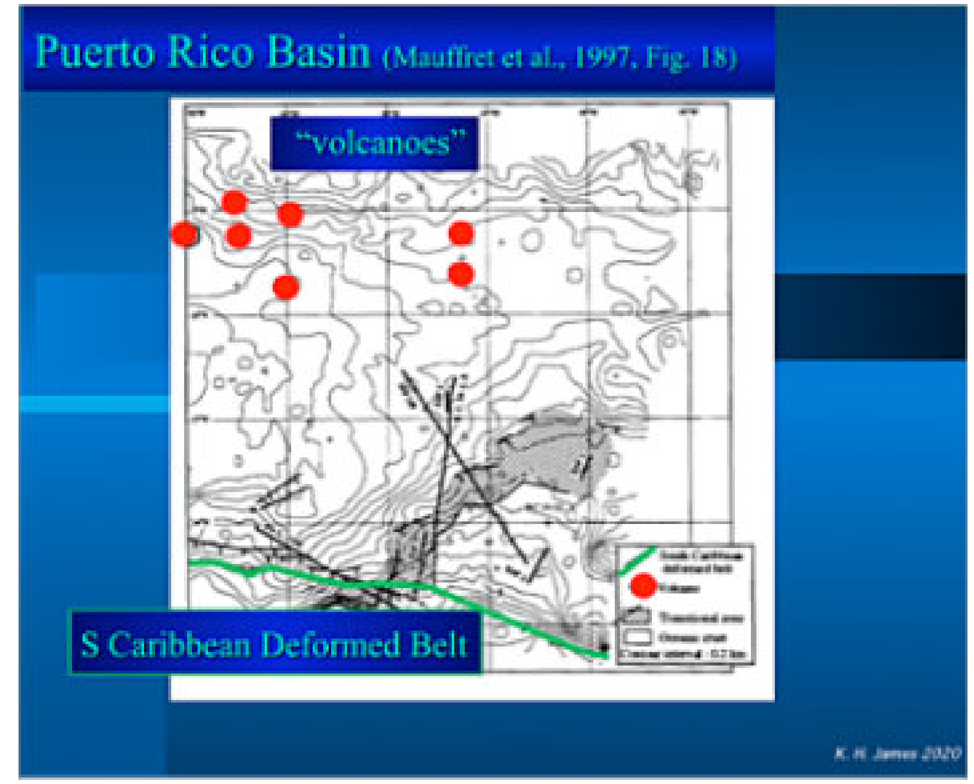

Figure 13. Volcanoes are interpreted in the Puerto Rico Basin (Mauffret & Leroy, 1997) could be diapirs.

The well Mosquitia 1, drilled south of Caratasca Lagoon, NE Honduras, penetrated a thick sequence of evaporites within a Cretaceous section (Mills & Hugh, pers. comm., see below).

Pinet (1972; Figs. 2, 4, 6, 7, 9) reported steep-sided diapirs on the sea floor NE of Honduras, connected to domal masses at depth, flanked by upturned beds Figure 14.

They do not show magnetic signature (rules out serpentinite). Written communication from Mills & Hugh (1970; quoted by Pinet (above)) shows a cluster of probable salt domes 75 km offshore east of Honduras. Pinet suggested that salt underlies the whole of the Honduran shelf. Correlation with salt in the Chiapas Basin of southern Yucatán corresponds to estimates of 300 km of sinistral offset along the Cayman Trough.

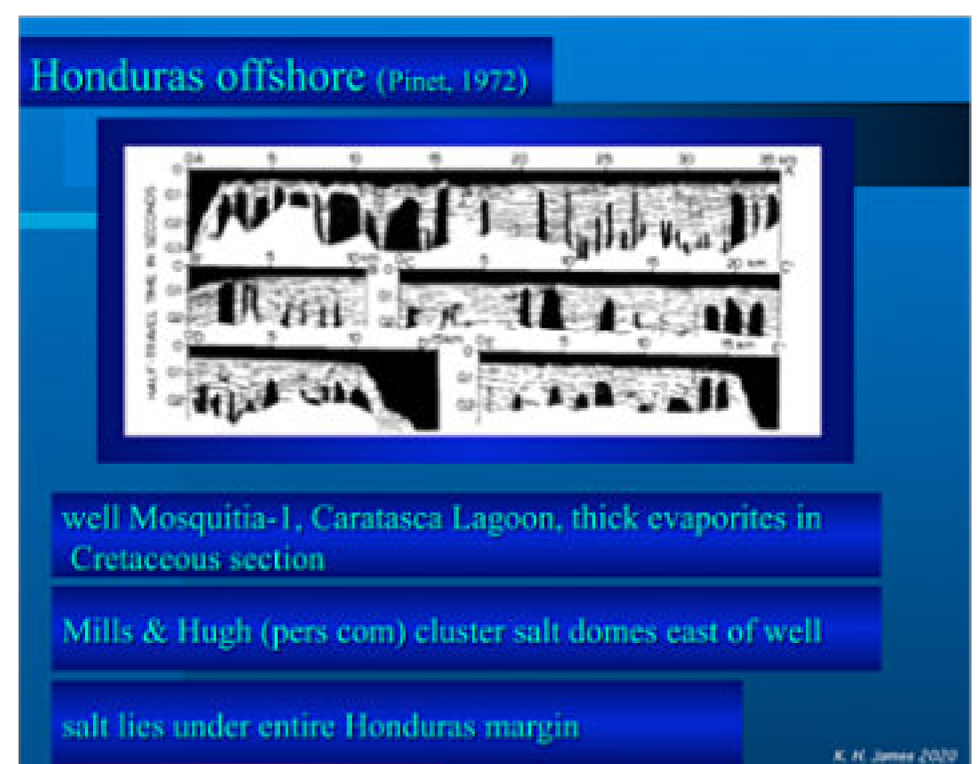

Figure 14. Sketches of seismic lines, offshore NE Honduras (Pinet, 1972). Oils from the Windsor-1 well in the onshore north coast region of Jamaica, are derived from a mature, very oil-prone type II to type IIS kerogen (Cameron, 2004). Biomarkers and carbon isotopes exactly match those of oil of the Belmopan Field in Belize. Both are very similar to Oxfordian Smackover derived oils of the central Gulf Coast region of the USA.

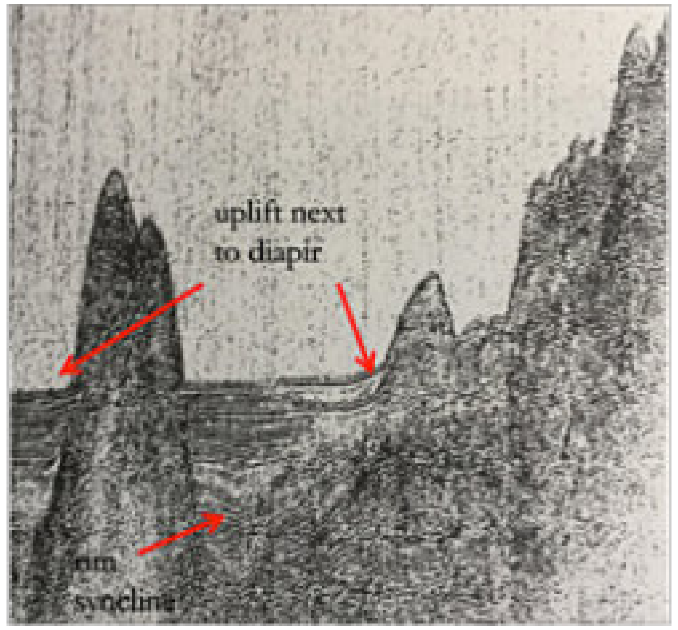

Figure 15. Seismic line over the Lower Nicaragua Rise (Rezak, 1972 – Case fig. 18)

This line show diapirs flanked by rim synclines and upturned adjacent beds (Rezak et al., 1972, Fig. 7).

Free-air anomalies generally within ±25 mgal of zero characterize central Yucatán, Colombian and Venezuelan basins. The Yucatán Basin lies between the Gulf of Mexico and the Caribbean, within the Middle American regional system of NW-SE reactivated ancient faults (James, Fig. 17).

Basement in the Yucatán Basin is defined as the unit below the deepest continuous seismic horizon, almost always marked by a distinct, high amplitude reflection or group of reflections. It occupies the same position relative to overlying sediments as does the late Cretaceous B" horizon of the Venezuelan Basin (Rosencrantz, 1990). Basement is irregular and has relief of more than 2 km. It "seems to have a volcanic origin" (Rosencrantz).

Figure 16. occurrences of possible salt, in the Yucatán basin, diapirs onshore N Cuba, Old Bahamas Channel, Bahamas.

Seismic data show an upper layer of reflections filling topography at the top of a lower layer with dipping reflections below horizon B. Rosencrantz stated "The geology is similar to that of the Colombian and Venezuelan basins". Data in the SW of basin (Rosencrantz, Fig. 7) show "horst and graben" features. Highs of around 10 km diameter have ponded sediments in between (withdrawal synclines?).

Diapir-like features are present in the centre of the basin, close to NE-SW trending faults of the La Trocha (LTF, Figure 17) system (Rosencrantz, 1990, figs. 10, 12, 15; interpreted as seamounts). Salt diapirs crop out where the fault crosses the north coast of Cuba and are seen in the Old Bahamas Channel and on the Bahamas platform to the north.

These data suggest that salt is present in the Yucatán Basin.

The Gulf of Mexico provides a model for the Yucatán and Caribbean basins. The related basins formed by extension as a NW trending zone pulled apart to the NW between inherited faults (Figure 17).

Seismic, gravity, magnetic and marine magnetotelluric data in the northern Gulf of Mexico indicate that autochthonous salt deposition was focused above a basement low (Bornatici, 2011). Hudec et al., (2014) wrote that a pre-existing crustal depression formed on hyper-extended continental and transitional crust. The thickest part of the salt estimated to have been 3 – 4 km. True basement is not seen.

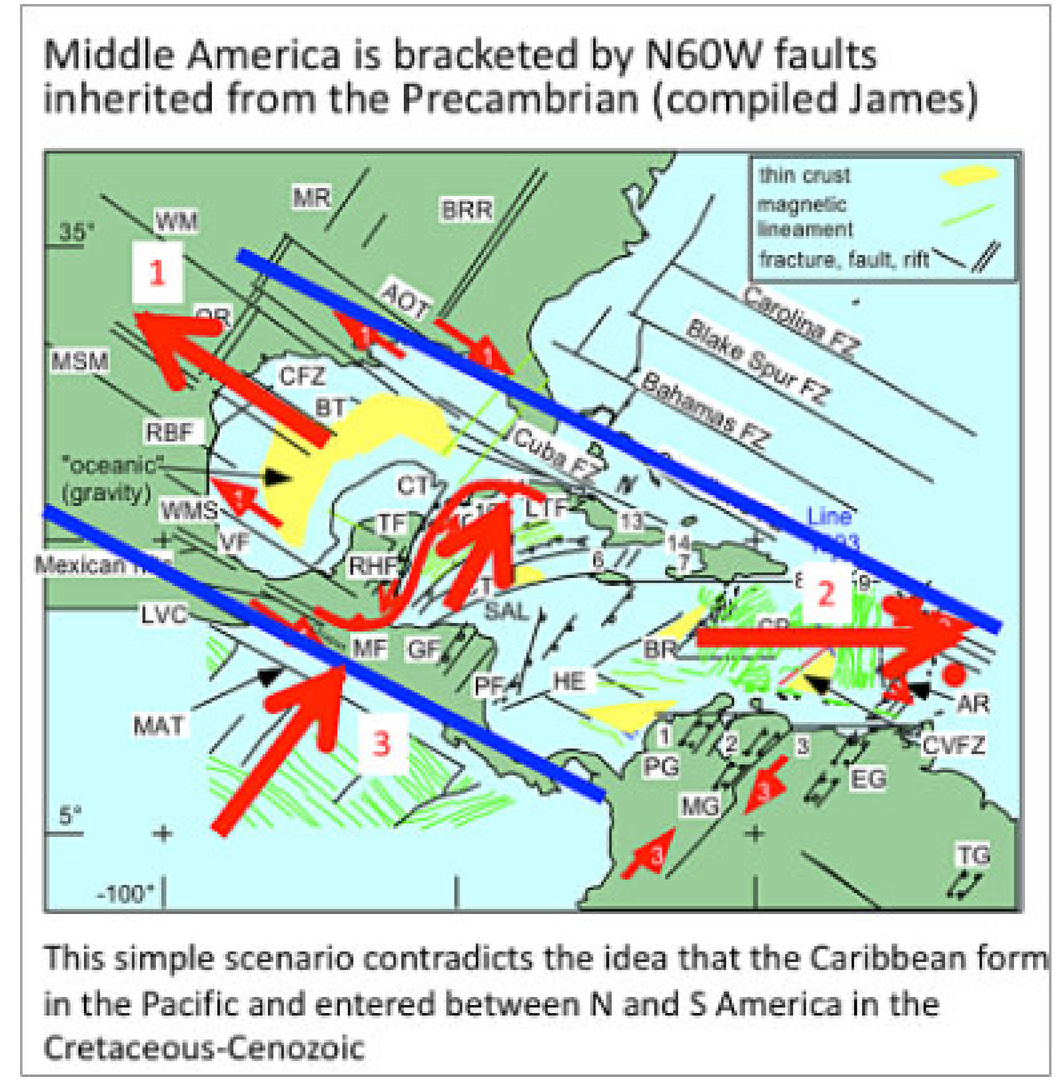

Figure 17. Regional tectonic fabric, Middle America (James)

Key:

AOT Arkansas – Oklahoma Transform; AR, Aves Ridge, BF, Beata F; BR, Beata Ridge; BRR, Blue Ridge Rift; BT, Brazos Transfer, CE, Campeche Escarpment; CFZ, CorsairFault Zone; CT, Catoche Tongue; CP; Caribbean Plateau; CVFZ, Central Venezuela fault zone; EG, Espino Graben; GF, Guayape F; HE, Hess Escarpment; LTF, La Trocha F; MAT, Middle America Trench; MG, Mérida Graben; MiG, Mississippi Graben; MF, Motagua F; MSM, Mohave-Sonora Megashear; OR, Oachita Rift; PF, Patuca F; PG, Perijá Graben – Urdaneta; RBF, Río Bravo fault; RGR, Río Grande Rift; RHF, Río Hondo F; SAL, San Andrés Lineament; TF, Ticul F; TG, Takutu Graben; TT, Texas Transform; TSZ, Tenochtitlan Shear Zone; TZR, Tepic–Zacoalco Rift; VF, Veracruz F; YC, Yucatán Channel. (1) Lower Magdalena Valley – Río Magdalena mouth; (2) Maracaibo Basin–Gulf of Venezuela; (3) Guarumen Basin (overthrust/hidden, revealed by seismic and drilling) – Golfo Triste; (4) El Hatillo – Cariaco; (5) Gulf of Paria – Carupano; (6) Windward Passage – Gonave Basin; (7) Asua Basin; (8) Puerto Rico – Hispaniola Mona Passage; (9) Anegada Passage. Green lines, magnetic anomalies (Gough 1967; Hall & Yeung 1980; Ghosh et al. 1984). Red arrows: 1 – extension towards the NW; 2 – eastward relative movement of the Caribbean. 3 - SW - NE shortening in the western Caribbean.

The Aves Ridge (Figs. 14, 15), at the eastern end of the Caribbean, west of the Lesser Antilles, is popularly thought to be an extinct Cretaceous volcanic arc, separated from the LA by opening of the Grenada Basin. However, there is no evidence that the ridge was a volcanic arc. There is no seismic indication of subduction and there is no accretionary wedge. The N-S trend of the ridge has never been explained in the literature. It fits the extensional strain of dextral movement along the NE boundary of Middle America (blue line in Figure 17). The Lesser Antilles radiate eastwards away from the ridge, overriding the Atlantic.

In 2016 the Russian organization Geology Without Limits recorded a seismic line over the southern Aves Ridge and Lesser Antilles. The data (Figure 14) show gas chimneys rising along the eastern margins of Aves highs and up to the sea floor, where biogenic? mounds occur.

In 1978 the vessel Researcher encountered a subsea oil slick at 600 feet depth, 10 – 30 miles wide, extending from west of Martinique towards the Sargasso Sea in the Atlantic (Harvey et al., 1979). Analysis of samples showed that the oil was crude, not processed, oil (Requejo & Boehm, 1985), probably from a massive submarine oil seep at 600 feet depth from an area on the Venezuelan platform where seeps are reported.

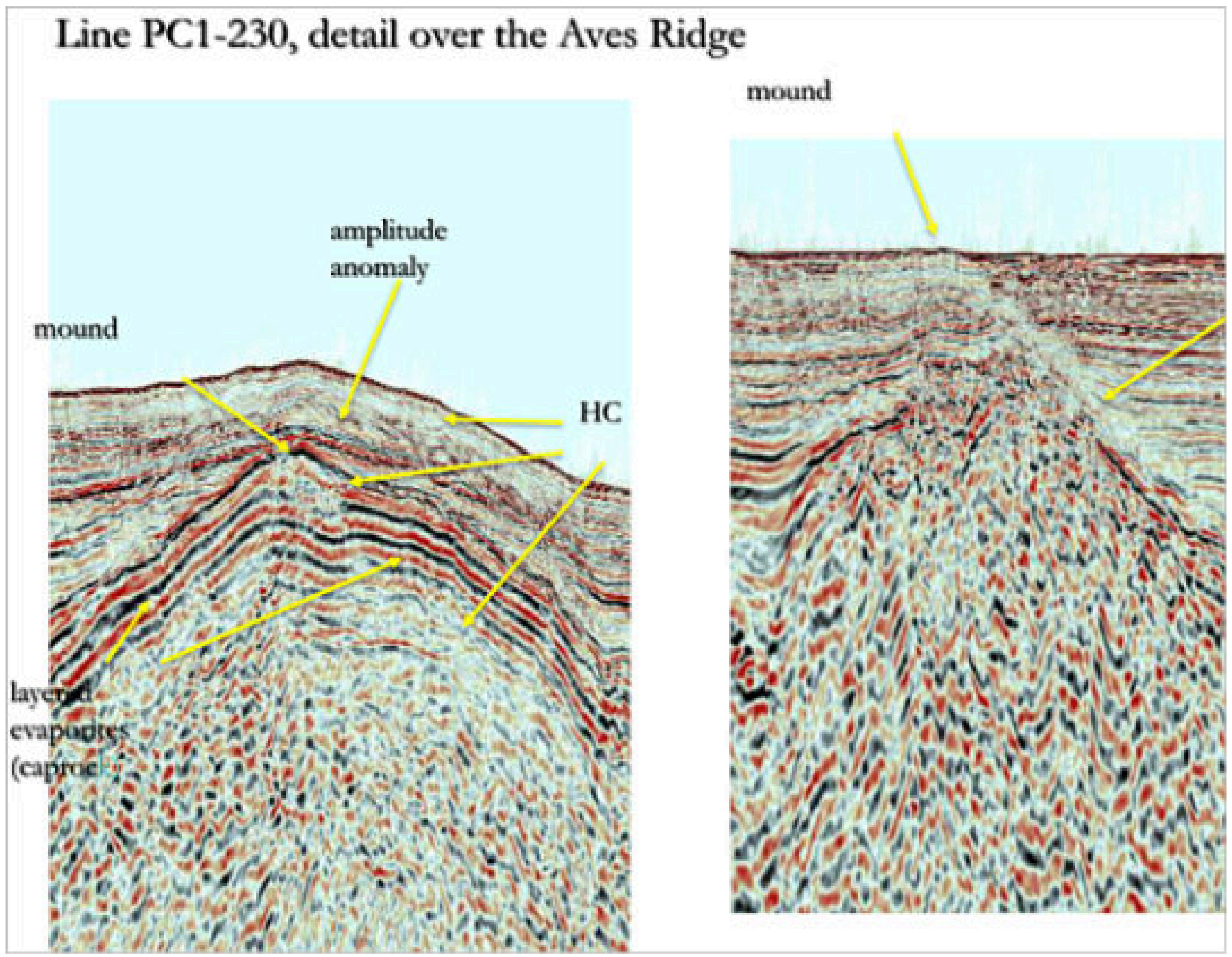

Figure 18, Detail from the western end of GWL Line PC1-230 over the Aves Ridge. Hydrocarbons rise along the eastern flank of the ridge and over the ridge crest. Biogenic? mounds form where hydrocarbons reach the seafloor. See also Bird, et al., 1999 (Figure 8), which shows highs flanked by synclines.

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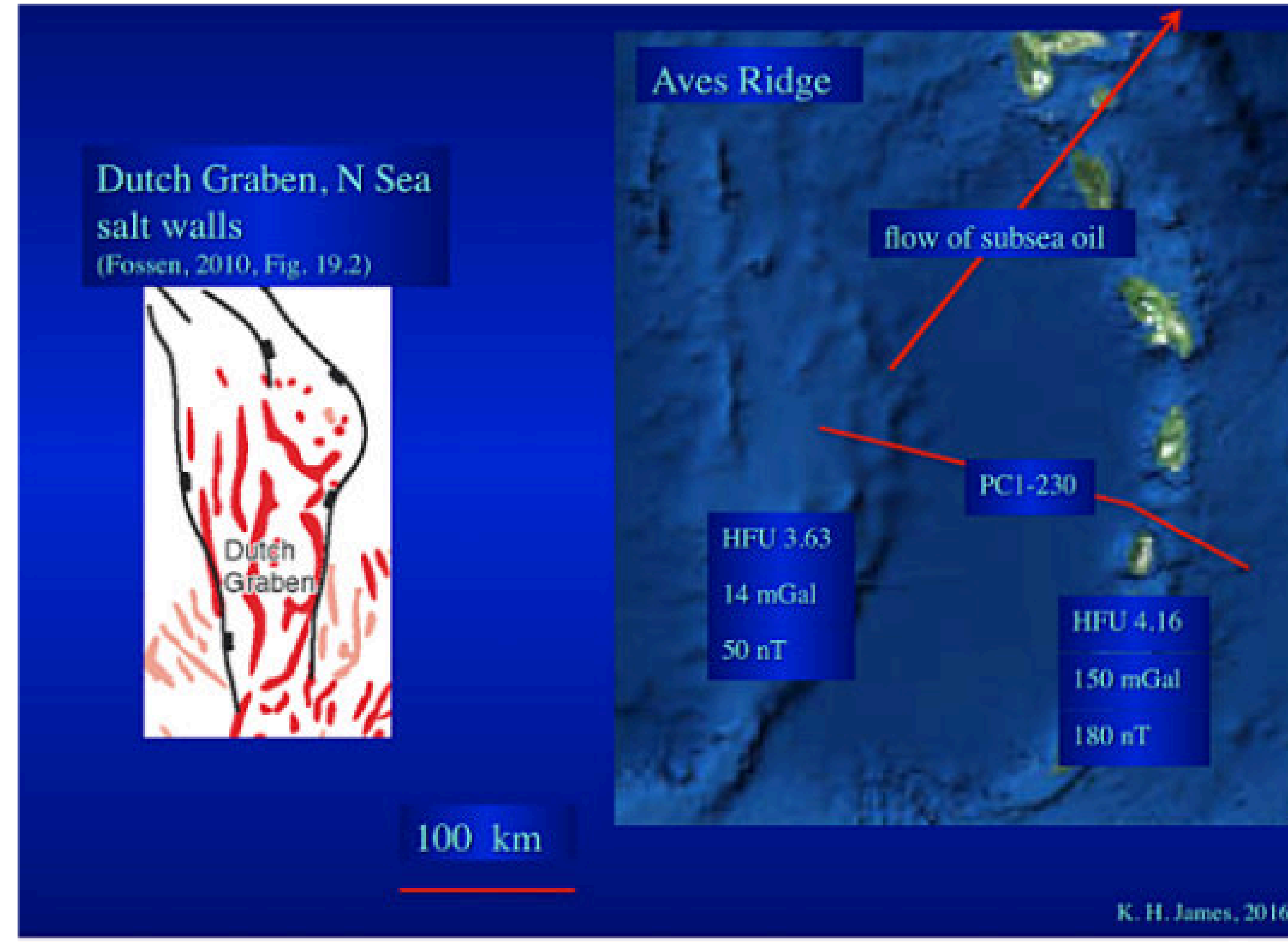

Figure 19. Map showing the locations of the sub-sea oil samples and GWL line PC1-230. For interest, it also shows a map of salt ridges in the Dutch Graben, North Sea (same scale). Gravity and magnetic values over the Aves Ridge are significantly lower than over the Lesser Antilles volcanic arc.

There is a strong relationship between the Caribbean, Cayman Trough, Yucatán, and Gulf of Mexico, Figure 13. They all lie within a zone of northwestward extension crossing southwestern N America, bounded by major NW trending fractures such as the Sunniland and Cuba fault zones in the northeast and the Mexican Rifts and Middle American Trench in the southwest, Figure 17.

Presence of volcanic Horizon B" in the Caribbean (and the Yucatán Basin?) perhaps reflects greater extension there than in the Gulf of Mexico.

The regional tectonic fabric (Figure 17) also includes NE trends, which show major dextral offsets north of the Gulf of Mexico. They appear as magnetic lineaments in the Caribbean along the eastern flank of the Beata Ridge and further east. Diebold (1999) related these to structure.

Major NE faults cross the Maya and Chortis blocks (Figure 17; again, extension) and negate complex models of their rotation.

The NW trending faults date back at least to the late Proterozoic – Palaeozoic (Thomas, 2014). Triassic Pangaean rifting followed the NE fabric, with rapid deposition of continental sediments in deep, elongate rifts (Manspeizer, 1988). We should expect to see this in Yucatán and Caribbean basement.

In summary, there are many reasons to relate the geology of the Gulf of Mexico, Yucatán and Caribbean basins. Many data indicate presence of salt in the Caribbean and Yucatán basins. Data provided by Diebold (1999) and others illustrated in this paper probably would improve with reprocessing.

Presence of salt in the Caribbean – Yucatán basins is important. 1). It is a major, unrecognized geological feature). It negates a Pacific origin for these areas (e.g. Pindell, 2021) and leads to paradigm change for understanding of Middle American geology. 3) The close relationship between salt, hydrocarbon source rocks and hydrocarbon accumulations means the basins could carry significant hydrocarbon reserves.

Seeps in the Gulf of Mexico are associated with regional salt (Faragó Botella et al., 2004; Durham, 2007). Valuable investigations of Caribbean salt would employ satellite data to search for oil slicks The Caribbean focus should start on the Honduran shelf, the eastern flank of the Beata Ridge, the Muertos Trough and the Aves Ridge.

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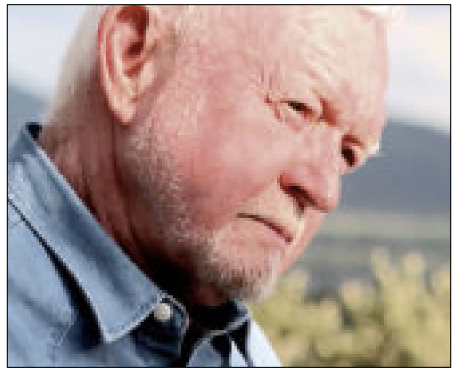
Discussion

There are many, complicated, models for the geology of the Caribbean. Most regard it as a large igneous province derived from the Pacific. None considers alternatives. None relates it to the Gulf of Mexico.

This article discusses data that suggest it carries a significant thickness (kilometres) of Triassic – Jurassic salt and shares history with the Gulf of Mexico and the Yucatán Basin within a regional belt of extension, bounded by reactivated Precambrian NW trending faults.



KEITH H. JAMES
Consultant Geologist,

C/Andia 5, 09346 Covarrubias, Burgos, Spain
16 Maeshenllan, Llandre, Bow Street, SY24 5DD, Ceredigion, Wales, UK

Tel: Mobile (0034) 676 120 984, (0044) 07955569335

BSc, Diploma Micropalaeontology, PhD Aberystwyth, Wales; MS Houston

Eight years teaching: *University of Houston, Texas*
University of Wales, Aberystwyth, Hydrocarbon University Venezuela

Twenty-six years Oil Industry Geologist

Worked with Shell in Gabon, Spain, Venezuela, UK (**Regional Geologist**, *Shell UK, London;* **International Geological Advisor** *Royal Dutch Shell, The Hague).* USA; **Chief Geoscientist and Senior Vice President Exploration**, *Conoco, International Exploration, Houston*.

Professional Profile:

I study the geology of the Caribbean, a widely recognised geological enigma

I challenge many Plate Tectonic tenets

I regard the Big Bang theory as puerile

Publications available on ResearchGate.

History

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