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Upper Paleocene to Lower Eocene Clay Deposits of the Red Bank Group, Northern Belize, Central America

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ABSTRACT

The informal upper Paleocene to lower Eocene Red Bank group crops out in several areas of the Cayo and Orange Walk districts of northern Belize including the study area of the present report, which is the area around the oil fields of Spanish Lookout and Never Delay. Previous studies, which assigned the wrong age to the Red Bank group, described the Red Bank as mainly a clay (or soft claystone) deposit containing minor carbonate and evaporite beds and nodules. However, our present research, which relies on new petrographic and cartographic techniques, revealed that the Red Bank group is a complex stratigraphic unit of open estuarine origin that has a depositional history closely linked to global climatic and eustatic events. Well-log correlation in the study area around the Spanish Lookout and Never Delay oil fields suggests that the Red Bank unconformably overlies the Upper Cretaceous Barton Creek limestones. In fact, the clay deposits of the Red Bank fill caverns and karstic features within the upper part of the Barton Creek limestones, and thick clay accumulations lie within karstic paleovalleys such as the long, northeast-trending, fault-bounded karstic valley within the study area.

INTRODUCTION

The Red Bank group is an informal, unconformity-bounded stratigraphic unit that crops out over large areas of northern Belize, as indicated by the geological maps of Cornec (2004, 2015). The Red Bank has a substantial thickness in some places (~500 m [~1640 ft] or more); yet the Red Bank is relatively thin—a few 10s of meters—in other locations (Bryson, 1975; King et al.,

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2018; Ricketts, 2020). The Red Bank is scattered over some areas of northern Belize, and the geographic distribution of this stratigraphic unit, especially the thick occurrences, appears to be a function of both its depositional paleogeography (a complex estuarine system developed upon inherited, erosional topography; Ricketts, 2020) and the subsequent erosion of the northern Belize. Outcrops of the Red Bank are relatively few and they tend to be heavily vegetated. The rolling hills on some local roads situated a few kilometers north of Spanish Lookout provide limited outcrops a few tens of meters thick (King et al., 2018). In the present report, we focus on subsurface samples and data for the Red Bank (Fig. 1). Like all stratigraphic units in Belize, the Red Bank has informal status (hence the lower case g in Red Bank group). For more detailed comments on this issue, the reader is referred to King et al. (2004 and 2018).

METHODS

In order to get an overview of the actual age, lithology, thickness, and distribution of the Red Bank, samples from 18 wells were obtained from the Department of Geology and Petroleum in Belmopan. Figure 1 shows the location of those wells; and Table 1 shows the details of samples requested. Well logs were obtained that showed the distribution of Red Bank clay in relation to the local stratigraphy. Figure 2 shows the distribution of Red Bank clays among selected wells in the study area. As reported by Ricketts (2020), subsurface samples, which were in the form of cuttings (or chippings as they are known in Belize) were analyzed for lithology, clay mineralogy, and calcareous nannofossil content in order to better understand the nature and origin of the whole of the Red Bank group. Lithologic study was accomplished by thin sectioning of selected well cuttings; clay mineralogy was determined by both air-dry and gycolation X–ray diffraction techniques (see Larsen et al., 2015). Calcareous nannofossils were extracted from selected well cuttings using standard paleontologic techniques and imaged by light microscopy. Depositional geometry of the Red Bank was determined by using selected geographic information systems methods, which are explained more fully in the results section below.

RESULTS

Lithologic Analysis and Clay Mineralogy

Cuttings from the study-area wells were biased toward grains having more durability, hence cuttings mainly composed of clay or claystone (the main lithic type in the Red Bank) were not fully represented in the materials studied. Clay content in cuttings, which were studied using petrographic thin sections ranged from 13 to 79 percent (Ricketts, 2020). The other components in cuttings were carbonate grains (range 8 to 99 percent), framework silicates (range 4 to 33 percent), and other minor detrital components noted in one or two wells, including chert fragments and benthic foraminifera (mainly miliolids) (see Ricketts, 2020).

Clay mineralogy was determined from analysis of clay cuttings from selected wells (Ricketts, 2020) and from a few surface samples (which have the same sample numbers as in King et al., 2018). Analysis of twelve subsurface samples that had significant quantities of clay revealed the presence of chlorite, illite, kaolinite, vermiculite, and montmorillonite (smectite). These clays have been identified previously as typical clay groups in the region (Scott, 1975; Thiry, 1993). X–ray diffraction (XRD) patterns were standardized to quartz (2–theta 26.66°) and clay groups identified based on d-values for both air-dried and glycolated samples (Ricketts, 2020). Table 2 shows the XRD peak values for clay minerals used for identifying clay groups. Figure 3 is a composite Venn-diagram representation of surface and subsurface samples showing the main clay minerals in common between the various sample locations. The common core group of Red Bank clays include illite, montmorillonite, and chlorite. The presence of this core clay group supports the notion of intensive tropical weathering of adjacent igneous and metamorphic bedrock (within the Maya Mountains) and alteration of these detrital clays in the shallow marine realm

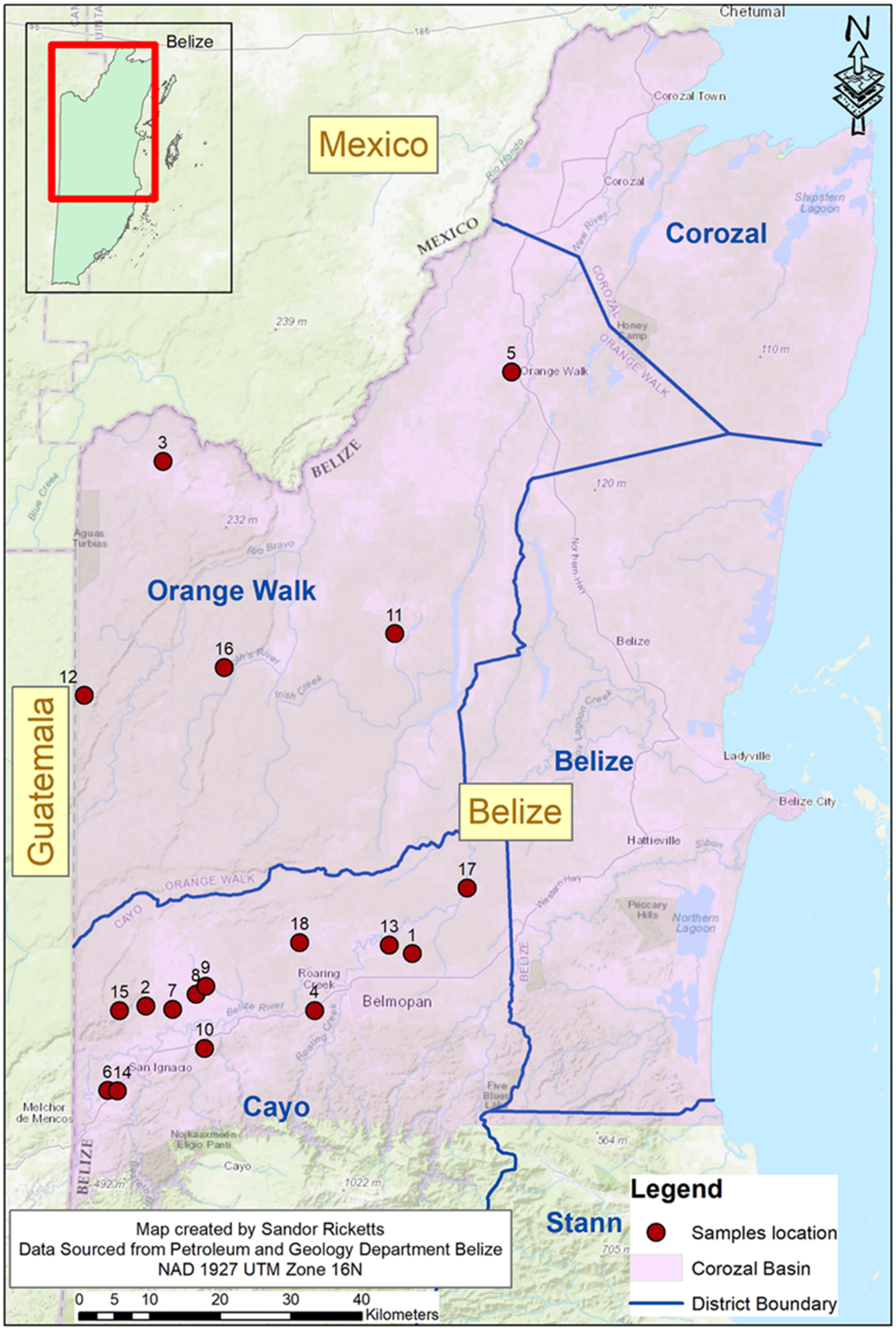


Figure 1. Map showing the four northern districts of Belize and the location of drilled wells (red dots) from which subsurface samples were obtained for the present study. Wells are numbered 1–18 here, and their names are listed in Table 1.

Table 1. A list of 18 wells from which 39 samples of cuttings used in the present study were obtained from the Belize Department of Geology and Petroleum, Belmopan. The locations of these 18 wells are shown on Figure 1. All these wells were drilled between 2006 and 2013.

Well no.	Well Name	Well ID	Quantity	Sample name	Depth range (ft)
1	Beaver Dam #1	BD #1	1	BD #1 A	1890–1920
2	Billy White #1	BW #1	3	BW #1 A BW #1 B BW #1 C	0–30 270–300 720–750
3	Blue Creek #2	BC #2	2	BC #2 A BC #2 B	90–120 780–810
4	Camalote #1	Cam #1	2	Cam #1 A Cam #1 B	1680–1710 1770–1800
5	Chan Pine Ridge #1	CPR #1	3	CPR #1 A CPR #1 B CPR #1 C	100–120 180–200 380–400
6	Kay Works #1	KW #1	1	KW #1 A	630–660
7	Mike Usher # 14	MU #14	1	MU #14 A	2520–2550
8	Mike Usher # 4	MU #4	2	MU #4 A MU #4 B	410–440 920–950
9	Mike Usher #6	MU #6	3	MU #6 A MU #6 B MU #6 C	200–230 890–920 1400–1430
10	Mount Hope #1	MH #1	3	MH #1 A MH #1 B MH #1 C	190–200 330–340 540–550
11	New Hope #1	NH #1	1	NH #1 A	690–720
12	Rio Bravo #1	RB #1	2	RB #1 A RB #1 B	420–480 570–600
13	Rock Dondo #1	RD #1	2	RD #1 A RD #2 B	1420–1450 1750–1780
14	San Ignacios #1	SI #1	3	SI #1 A SI #1 B SI #1 C	120–140 280–300 540–560
15	Santa Familia #1	SF #1	2	SF #1 A SF #1 B	570–600 1390–1400
16	South Canal Bank #1	SCB #1	3	SCB #1 A SCB #1 B SCB #1 C	390–420 720–750 930–950
17	Toucan #2	Tou #2	3	Tou #2 A Tou #2 B Tou #2 C	30–60 330–360 480–510
18	Valley of Peace #2	VP #2	2	VP # 2 A VP #2 B	540–570 750–780

(Douglas, 1993; Barthelmy, 2014). Illite being more common than kaolilite may suggest eolian input of illite-bearing fines (Hyeong et al., 2005).

Previously, Flores (1952) wrote that the Red Bank is composed of “bentonitic clay admixed … with finely divided glass laths of volcanic origin.” And, Cornec (2015) wrote in the legend to his geological map of Belize that the Red Bank’s bentonitic clays were “likely derived from weathering of volcanic ashes." We did not find any volcanic glass fragments or any specific evidence of former volcanic ash in the Red Bank. There may be beds (or facies) within the Red Bank elsewhere in northern Belize that contain these volcanically derived components, but they were not sampled by us in the present study.

Nannofossil Age Determination and Global Events

Although the Red Bank has been previously reported as Miocene-Pliocene (Flores, 1952) and upper Eocene to Miocene (Cornec, 2004; 2015), the present study identified the chronostratigraphic position of the whole of the Red Bank group as upper Paleocene to lower Eocene. Calcareous nannofossils, which represent global biostratigraphic zones NP9 and NP10 (Martini, 1971; Okada and Bukry, 1980; Agnini et al., 2017), were recovered from several samples (Table 3). Key nannofossils recovered from the Red Bank included *Prinsius bisuleus*, *Toweius eminens*, *Toweius tovae*, and *Heliolithus cantabriae*. This biochronostratigraphic result supports earlier work (King et al., 2018), which showed the lower part of the Red Bank was also upper Paleocene to lower Eocene (Fig. 4).

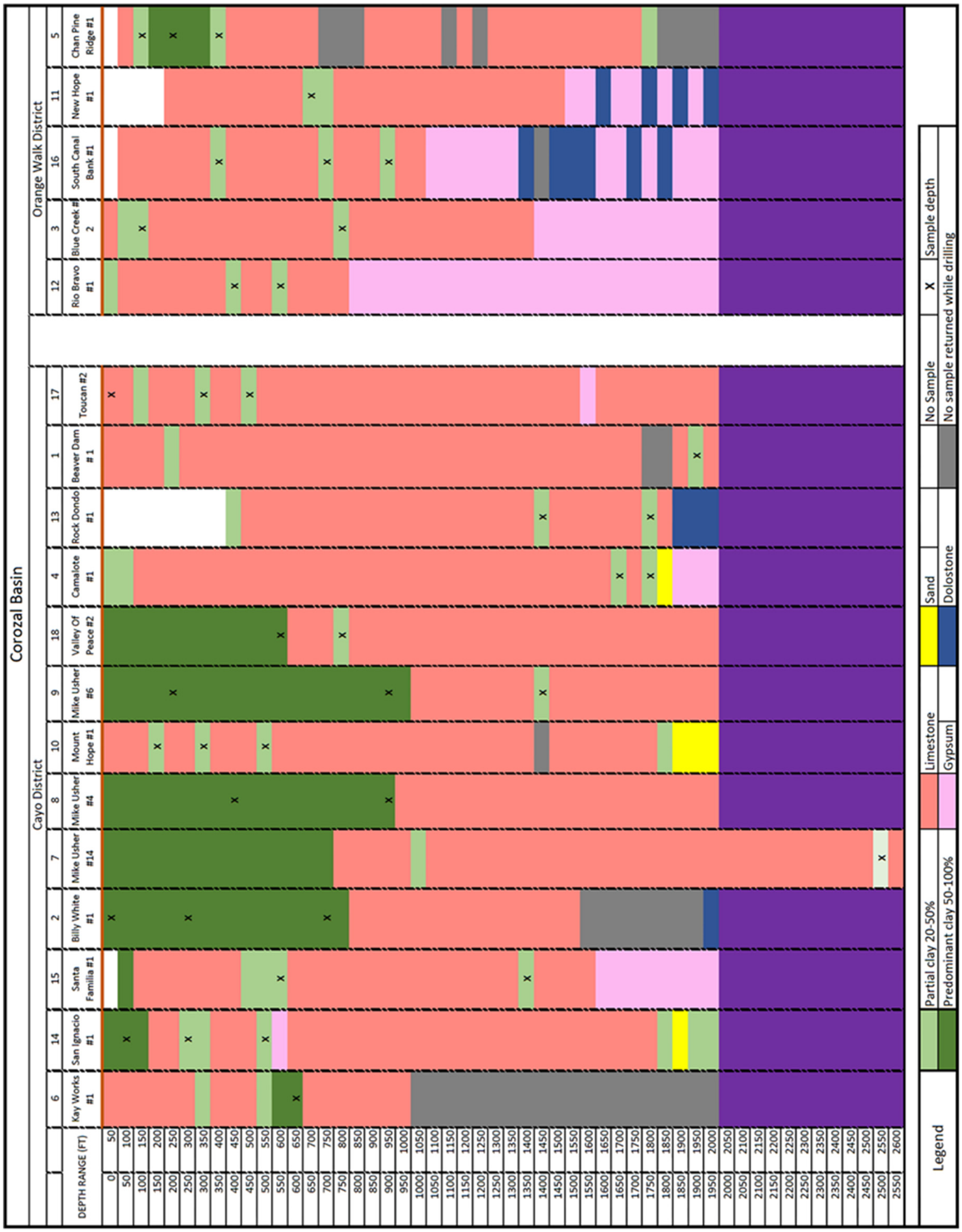
The confirmed late Paleocene to early Eocene age range for the whole Red Bank means that this stratigraphic unit encompasses the Paleocene-Eocene Thermal Maximum (PETM) global climatic event, as well as the time interval of some significant eustatic high and low sea-level stands (see the global sea-level curve in Miller, 2009; also see Miller et al., 2005). Apparently, evidence for the effects of the PETM in Belize are evaporite-bearing beds within the Red Bank, including layers with decimeter-scale, inter-grown crystals of gypsum and anhydrite. These beds may be coeval with thicker evaporite deposits in the nearby state of Campeche, México (i.e., the Icaiche Formation; Perry et al., 2021).

Eustatic low sea-level stand within the Red Bank can be putatively correlated with karstic development within the underlying limestone; whereas eustatic high sea-level stand within the Red Bank can be related to transgressive sedimentation of the thick stratigraphic sections of the Red Bank clays (Fig. 5). The Red Bank's basal nannofossils indicate that the initial clay deposits marking the end of karst development were deposited during a period of global low stand in sea level (c. 58–60 Ma; Fig. 5). Hence, it is envisioned that this low stand facilitated exposure to meteoric water, facilitating dissolution of the underlying faulted and fractured limestone (i.e., the Barton Creek formation), and development of a local karstic valley system, as described in the depositional geometry below. This scenario is supported by our XRD analyses, noted above, which indicates components of the basal Red Bank clay deposits were generated by intensive weathering of nearby crystalline and metamorphic rocks.

The eustatic low may have been intensified by coeval tectonics in the region. A period of Gulf-Caribbean sea-level drawdown during Paleogene is hypothesized to have occurred when the Cuban arc collided with the Yucatán and Bahamas carbonate platform; thus, perhaps isolating the Gulf of Mexico from the rest of world's oceans (see Rosenfeld and Pindell, 2003; Rosenfeld, 2016). Such a drawdown may be related to submarine canyon development in the region, including Belize, and may have intensified karstic valley development in the study area of northern Belize.

Depositional Geometry and Depositional Environments

Analysis of the thickness and distribution of the Red Bank clays in the study area around Spanish Lookout and Never Delay oil fields, shows that there is a karstic paleo-valley of substantial size, which trends to the northwest and is filled by Red Bank clays (Fig. 6). This paleo-valley, which likely drained the surrounding Maya Mountain Ridge, also extends into adjacent Guatemala (Ricketts, 2020). In this karstic paleo-valley, the Red Bank is found at maximum depth of approximately 549 m (~1800 ft) within a long, linear depression. This depression shows no surficial expression that is discernable on the most recent (i.e., 2020) Digital Terrain Model (DTM) of Belize or in any other three-dimensional rendering. However, the deposit can be dis-



Corozal Basin
Cayo District
Orange Walk District
DEPTH RANGE (FT)
6 Kay Works #1
14 San Ignacio #1
15 Santa Familia #1
2 Billy White #1
7 Mike Usher #14
8 Mike Usher #4
10 Mount Hope #1
9 Mike Usher #6
18 Valley Of Peace #2
4 Camalote #1
13 Rock Dondo #1
1 Beaver Dam #1
17 Toucan #2
12 Rio Bravo #1
3 Blue Creek # 2
16 South Canal Bank #1
11 New Hope #1
5 Chan Pine Ridge #1
Legend
Partial clay 20-50%
Predominant clay 50-100%
Limestone
Gypsum
Sand
Dolostone
No Sample
No sample returned while drilling
X Sample depth

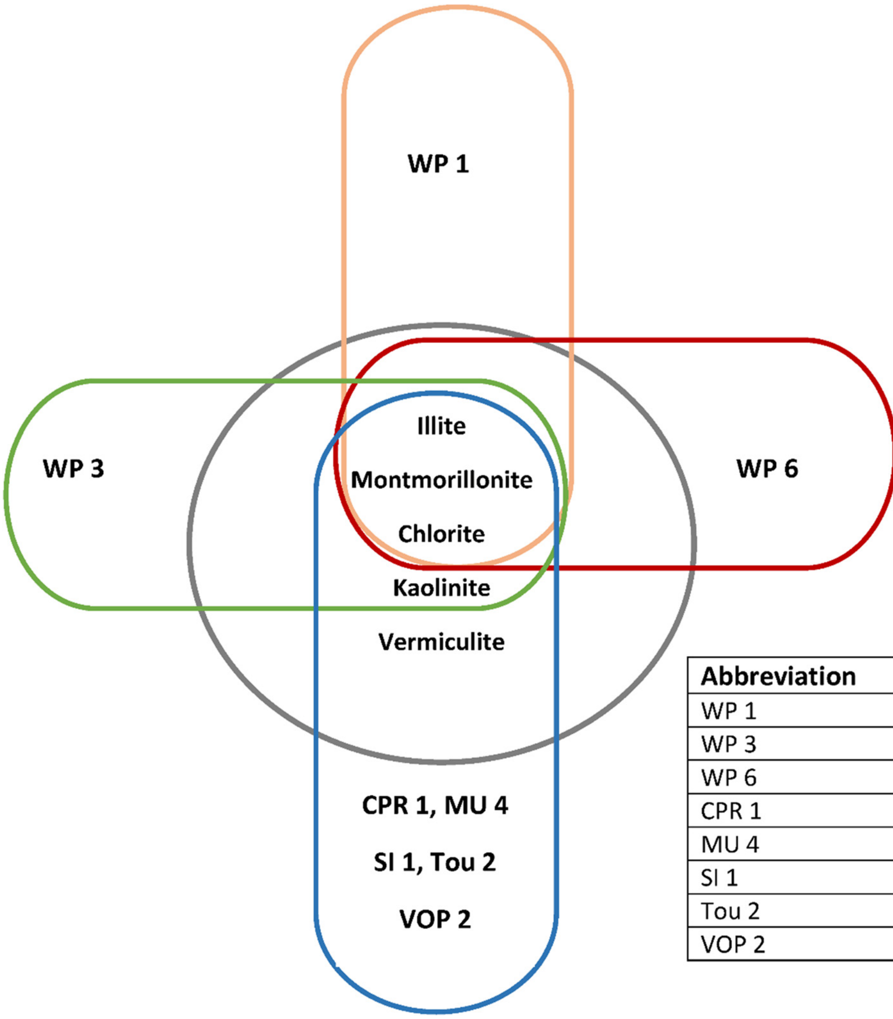
(FACING PAGE) Figure 2. Non-correlated, west-to-east serial arrangement of the mud logs from wells used for the present report (modified after Ricketts, 2020). Well numbers correspond to wells shown on Figure 1 and listed in Table 1. Lithologies are color-coded (see legend at the bottom); bases and tops of the informal, named stratigraphic units are not marked. However, the limestone (pink) is Barton Creek formation; formations below the Barton Creek, i.e., the Yalbac, contain gypsum, dolostone, and sand (stone). The two green shades are Red Bank group clays. 'Partial clay' intervals within the Barton Creek are interpreted as karstic fill by Red Bank clays and claystones, as noted in the text. Vertical scale is in feet; and the lithologic data are binned at 50 ft intervals owing to the original sample recovery method. Purple at the base of most sections indicates obscured proprietary data. Some of these data were provided by Horizon Well Logging, Inc. Note the wide variation in thickness of the main clay deposits of the Red Bank group (darker green). Top of the mud logs is the ground surface. Small x marks sampling locations for this study (see Table 1).

Table 2. X–ray diffraction pattern peak values for the five main clay minerals of the Red Bank group. These peak values were evident in analyses of the present study's samples and thus used for identifying the clay groups listed below. Peak spacing is in angstroms (Å).

Test	Group	Peaks (Å)		
		(001)	(002)	(003)
Air-dry	Chlorite (Fe)	14.2	7.11	4.74
Glycol				
Air-dry	Illite	10.1	5	3.38
Glycol				
Air-dry	Kaolinite	7.15	3.58	-
Glycol		7	3.5	-
Air-dry	Montmorillonite	15	5	3.75
Glycol		16.9	8.46	5.64
Air-dry	Vermiculite	14.4	7.6	3.58
Glycol				

cerned by merging the DTM with the elevation raster of the unconformity surface between the Red Bank and the underlying Barton Creek limestones (for additional details on this process, see Ricketts, 2020). Preliminary analysis of the whole of northern Belize suggests that there were many such paleo-valleys incised at this time (see Ricketts, 2020).

Multiple depressions and peaks can be identified within the underlying limestone based on the digital model generated for the unconformity, and the largest of these depressions is extrapolated from the western cluster of wells (see Figure 1). The Red Bank's digital model gives a general overview of the deposit in three dimensions; therefore, in order to generate two-dimensional representations of the unconformity, three cross-sections were generated (Fig. 7) within which varying boundary gradients can be observed. Steep boundary gradients along the northeastern and southeastern limit of the valley-filling deposit in each cross-section coincide with the location of previously reported faults. To check this interpretation, the inferred Red Bank geometry and fault locations were confirmed by reviewing proprietary and non-proprietary seismic lines, as reported by Ricketts (2020).



Abbreviation	Sample name
WP 1	Way Point 448_SP1
WP 3	Way Point 448_SP3
WP 6	Way Point 449 SPB
CPR 1	Chan Pine Ridge 1
MU 4	Mike Usher 4
SI 1	San Ignacio 1
Tou 2	Toucan 2
VOP 2	Valley Of Peace 2

Figure 3. Venn-type diagram showing results of XRD analysis on both outcrop and subsurface samples. Surface samples were collected in the Spanish Lookout area by King et al. (2018) and their sample names are the same as in that paper. Subsurface samples were collected from wells used in the present study (see Table 1). The main five clay minerals found in the present study are listed, and the overlapping zone (i.e., the core group) consists of the three clay minerals illite, montmorillonite, and chlorite. From the clay mineral analysis of Ricketts (2020).

The Red Bank's calcareous nannofossil suite and its textural and mineralogical composition, including the illite-montmorillonite-chlorite dominated suite of clays, indicate that deposition likely occurring in a relatively shallow, low-energy marine environment. Previously, King et al. (2018) speculated that the Red Bank depositional environment was akin to "vast modern tidal flats and adjacent very low-energy subtidal areas," which is seen today on the European North Sea coast. However, the valley-filling geometry of Red Bank clay deposits, as described above, suggest that the depositional environment was more like an open estuarine system. This interpretation is consistent with inundation of inherited topography, such as karstic valleys, as a re-

Table 3. Age-diagnostic taxa (calcareous nannofossils) that were identified in Red Bank samples of the present study. Well names and numbers are given in the column titled 'sample number;' sample numbers match those in Table 1. Biozones were classified according to Martini (1971), as modified by Okada and Bukry (1980). Underlined taxa represent the oldest diagnostic taxa. Samples that were barren are not listed.

Sample #	Sample number	Age-Diagnostic Taxa	Martini (1971) biozone	Okada & Bukry (1980) biozone	'sub-Epoch'	Stage
2	CPR #1 B	<u>*Prinsius bisulcus*</u>, *Prinsius matinii*	NP10	CP9	early Eocene	Ypresian
3	CPR #1 C	<u>*Prinsius bisulcus*</u>, *Prinsius matinii, Toweius eminens*	NP10	CP9	early Eocene	Ypresian
9	SI #1 A	<u>*Toweius eminens*</u>, *Toweius callosus, Toweius pertusus*	NP10	CP9	early Eocene	Ypresian
29	VOP #2 A	<u>*Heliolithus cantabriae*</u>, *Prinsius bisulcus, Prinsius martinii*	NP9	CP8	late Paleocene	Thanetian
30	VOP #2 B	<u>*Prinsius bisulcus*</u>	As young as NP10, likely older	As young as CP9, likely older	early Eocene	Ypresian
32	MU #6 A	<u>*Ericsonia subpertusa*</u>, *Prinsius bisulcus, Toweius eminens*	NP10	CP8	early Eocene	Ypresian
33	MU #6 B	<u>*Cruciplacolithus frequens*</u>, *Prinsius bisulcus, Toweius callosus, Prinsius martinii*	NP10	CP8	early Eocene	Ypresian
35	MU #4 A	<u>*Heliolithus cantabriae*</u>, *Prinsius bisulcus, Discoaster multiradiatus, Toweius tovae*	NP9	CP8	late Paleocene	Thanetian
36	MU #4 B	<u>*Ericsonia subpertusa*</u>, *Prinsius bisulcus, Toweius pertusus, Toweius callosus*	NP10	CP8	early Eocene	Ypresian
38	BW #1 B	<u>*Toweius eminens*</u>	NP10	CP8	early Eocene	Ypresian
39	BW #1 C	<u>*Prinsius bisulcus*</u>, *Toweius callosus*	NP10	CP8	early Eocene	Ypresian

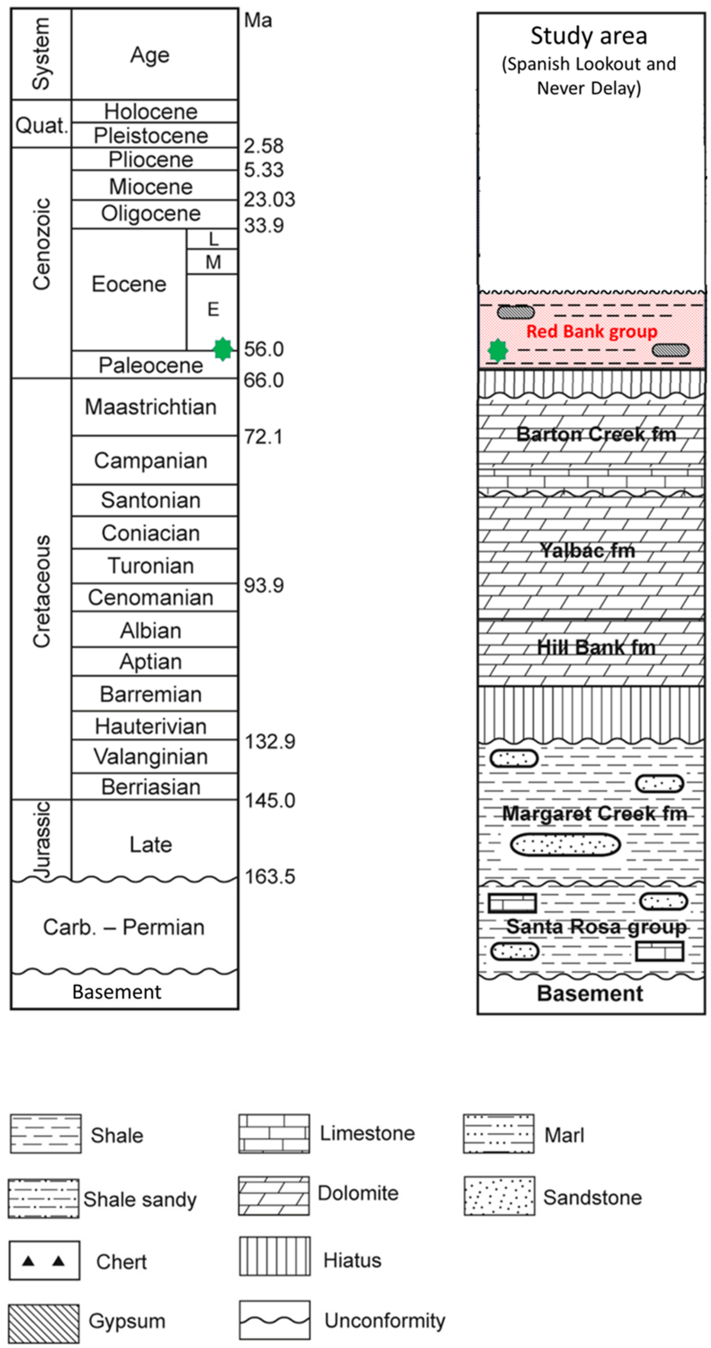


Figure 4. Stratigraphic column of the present study area (i.e., the area around Spanish Lookout and Never Delay oil fields) and its chronostratigraphy (modified after King et al., 2018). This stratigraphic column is aligned with respect to the global chronostratigraphic column at left in accord with the biostratigraphy of the Red Bank group as reported here (noted by green dots). And, similarly the other stratigraphic units below the Red Bank conform to the latest chronostratigraphic correlations (see King et al., 2018). The hiatus directly below the Red Bank relates to the episode of karst development as noted in the text.

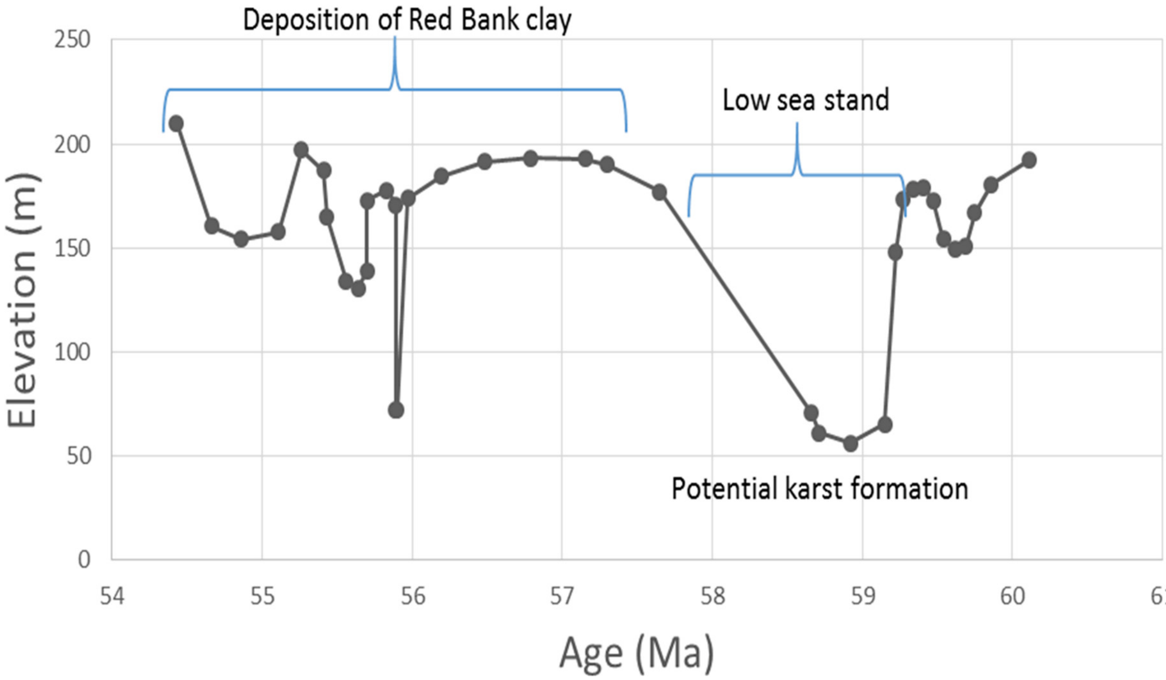


Figure 5. Eustatic sea-level curve in meters of elevation above present (data points from Miller, 2009) (from Ricketts, 2020). In this rendering of the data, points were plotted for the pertinent portion of the Early Cenozoic global sea-level curve. Key events in the history of Red Bank sedimentation are labeled here, including the low-stand associated with karstic development and transgressive deposition of the karst-filling and valley-filling Red Bank clays (see text for explanation).

sult of rising sea-level during deposition of the Red Bank (discussed above). An estuarine system for the Red Bank also helps to explain the irregular distribution of this stratigraphic unit and the wide, local variations in its thickness.

SUMMARY AND CONCLUSIONS

The Red Bank group has been a rather enigmatic stratigraphic unit of northern Belize since the publication of Flores' 1952 report in which he gives this clay deposit its name and provides a brief one-page description. Flores was unaware of the thickness of the Red Bank, but subsequent reports on exploratory drilling through the Red Bank indicated its substantial thickness in some places, minimal thickness or absence in others, and the unconformable karstic contact with the underlying limestones (reviewed in King et al. (2018) and in Ricketts (2020)).

The Red Bank is noteworthy in that its clays and claystones of varying thickness, as well as the basal karstic unconformable contact, pose substantial challenges for useful processing of some seismic lines in northern Belize (King and Petruny, 2012). In this regard, the Red Bank is sometimes referred to (wrongly) in exploration reports as "the Miocene clay." We suggest that the depositional model presented here, including the hypothesis about the Red Bank's geometry with respect to paleo-valleys, may be helpful in future efforts at more accurate seismic exploration processing in the study area.

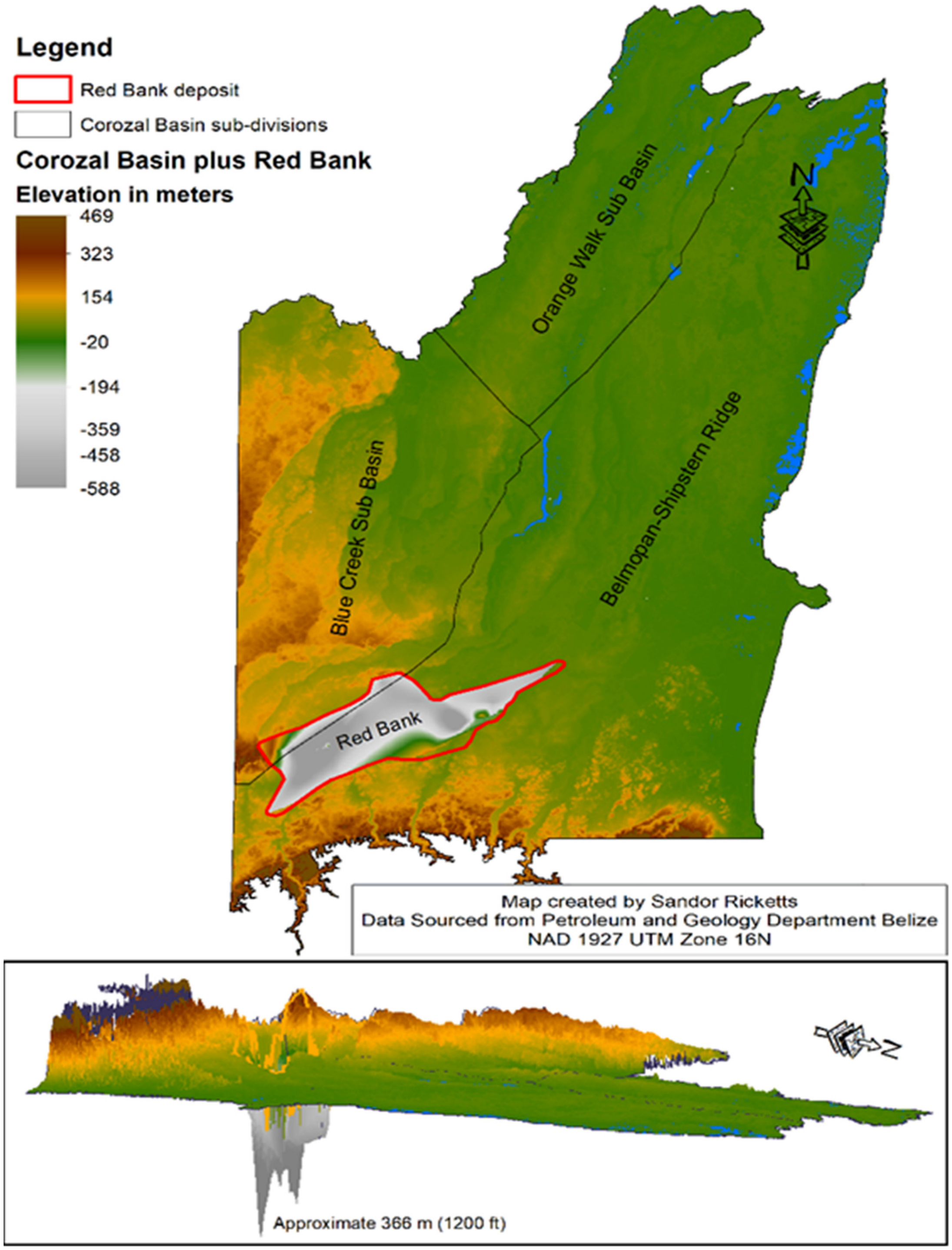


Figure 6. Digital elevation model showing a northeast-trending karstic paleo-valley of substantial size (grey area labeled 'Red Bank'), which is filled by Red Bank clays (from Ricketts, 2020). This model was developed using the process described in the text (see also Ricketts, 2020). Inset perspective view shows depth of the paleo-valley. Elevation color scale in meters.

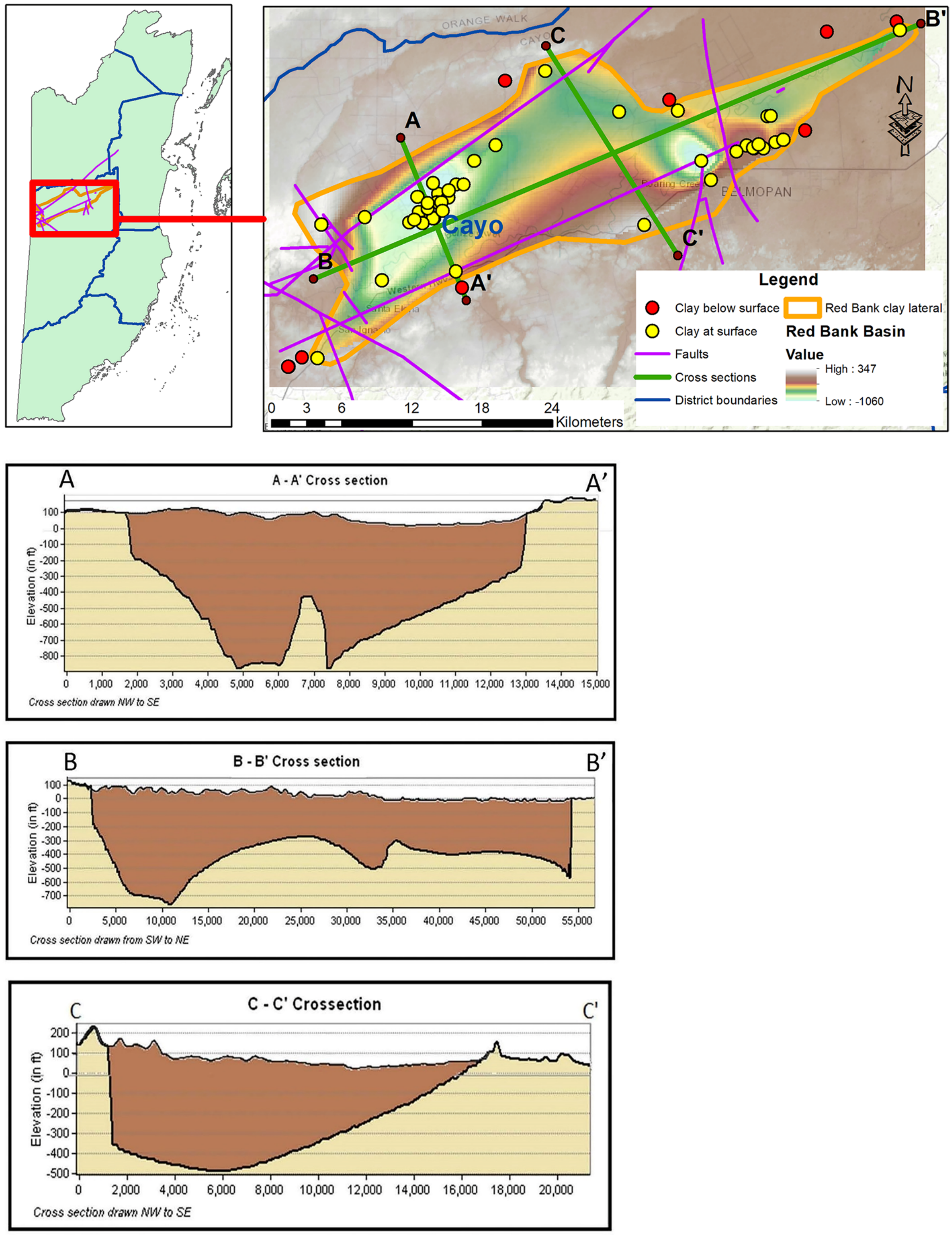


Figure 7. At top: map showing the distribution of Red Bank clay and its thickness within the paleo-valley feature shown in Figure 6 (modified after Ricketts, 2020). Map also shows lines of cross-sections A–A', B–B', and C–C'. In the three cross sections, Red Bank clay filling of the paleo-valley is shown in brown. The sharp boundaries at the sides of the clay fillings in each instance are likely fault boundaries, except on the eastern side of B–B' where the data are insufficient to make that determination. Source of data is the Department of Geology and Petroleum, Belmopan, Belize.

Our conclusions are rather simple. The present report shows that the whole of the Red Bank group is upper Paleocene to lower Eocene and that this stratigraphic unit is mostly of open estuarine origin, consisting mainly of clays. These clays were deposited initially in karstic voids within the underlying limestones, and subsequently in shallow estuarine channels, during a eustatic sea-level rise. The Red Bank depositional system inherited a topography dominated by karstic features including deeply incised karst valleys, and that topography strongly controlled the areal distribution of Red Bank deposition.

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