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BATHYMETRIC AND HIGH-RESOLUTION MULTI-CHANNEL SEISMIC REFLECTION DATA ANALYSIS OF RAS EL BURKA SUBMARINE PROLONGATION ALLUVIAL FAN, GULF OF AQABA, EGYPT

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ABSTRACT

At the entrance to Wadi El Mahash El Asfal, Ras El Burka submarine prolonged alluvial fan was constructed on the western side of the Gulf of Aqaba. The fan's growth pattern, sedimentation, and structure are all attempted to be explained in this paper. Geophysical studies in the northern Red Sea and the Gulf of Aqaba were conducted during the cruise M44/3 in 1999 and form the basis for the research of the Ras El Burka region.

The Sinai Peninsula hills and mountains that had been eroded provided the sediment for this fan, and during the infrequent rains, the sediment was transported to the Gulf of Aqaba via Wadi El Mahash El Asfal. Sedimentary facies inside the Ras El Burka fan were interpreted using high-resolution multi-channel seismic profiles, which revealed variable seismic facies. The predominant seismic facies exhibit reflections of moderate to high amplitude, which are understood to be gravel to sand deposits. Thus, a coarse-grained, sand-rich turbidite system may be used to describe the Ras El Burka submarine fan. Since there are still active faults and steep slopes, many of these slumps and slides are likely caused by these factors on the sharp slope, the walls of the canyons, and the fault scarps of the fan. The interaction between sediment inflow, tectonism, and climatic conditions determines the patterns of sedimentation in the fan.

Key Words: Gulf of Aqaba, Sinai Peninsula, Wadi El Mahash El Asfal, Ras El Burka, Alluvial Fan, Submarine Fan.

INTRODUCTION

At the mouth of Wadi Al Mahash Al Asfal, a small submarine alluvial fan occupies the region of Ras El Burka (Fig. 1). This wadi, which pierces the highlands and mountains of the Sinai Peninsula, delivers fan sediments. 20 km long and 10 km wide, the Ras El Burka submarine alluvial fan is situated between latitudes 29° 07' N and 29° 18' N. According to bathymetric profiles, a few braided submerged channels that vary in width and depth (1.6–0.3 km wide and 45–25 m depth) cut through the surface of the Ras El Burka submarine alluvial fan. Some of these canals underwent thalweg conversions, going from straight following to meandering.

Major slumps may be seen along the continental slopes and at the outer fan flanks **(Salem, 2003)**. The development and expansion of the Ras El Burka fan is the primary subject of this paper's investigation, which is based mostly on the interpretation of high-resolution seismic reflection airgun profiles. During cruise M44/3 in 1999, these profiles were gathered from this region (Fig. 2-a).

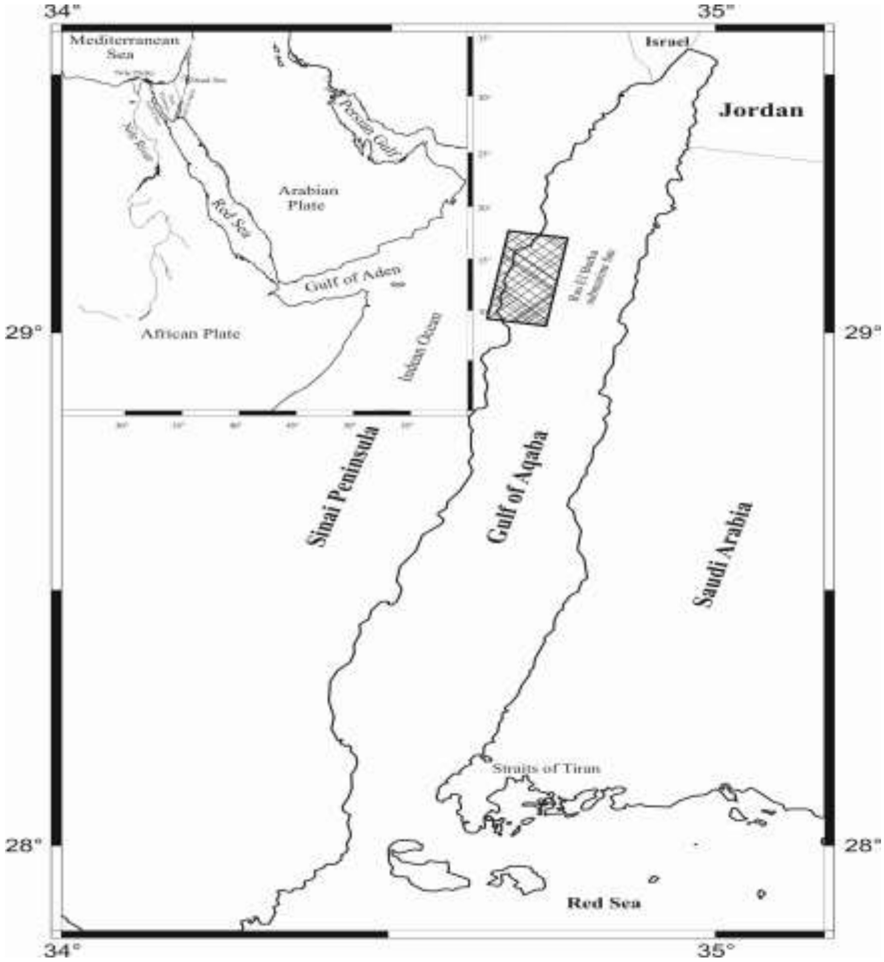

Fig. 1: Overview map of the Gulf of Aqaba showing the location of the Ras El Burka area.

In general, investigations of coarse-grained, sand-rich fans in the California Borderland and small Piedmont basins in Europe **(Normark, 1970; Mutti and Ricci-Lucchi, 1972)** served as the formation for the initial submarine fan Based on grain size and feeder system, **Reading and Richards (1994)** classified underwater fans/turbidite systems into twelve types, resulting in fine- and coarse-grained turbidite systems. Mud-rich, mud/sand-rich, sand-rich, and gravel-rich environments make up the grain size components. Point source, multiple source underwater ramp, and linear-source slope apron are the feeding systems. Oceanographic studies of the Amazon fan **(Damuth and Kumar, 1975)** and the Mississippi fan **(Moore *et al.,* 1978)** served as the origin and structure for the first models for the larger, finer-grained, mud-rich underwater fans.

According to **Stow *et al.,* (1985)**, the predominant depositional processes do not solely account for the sedimentation and facies distribution in turbidite systems. Any deepwater depositional system's operations respond to a range of external driving factors, including sediment supply and type, climate, tectonic setting and activity in the receiving basin and the hinterland, as well as changes in sea level.

While the response of sedimentation depends on the rate of relative sea-level change (eustatic sea-level, subsidence), the rate of sediment transport, the rate of sediment supply, and the size of the sediment grain, changes in the sediment supply in clastic depositional systems are frequently associated with conditions in hinterland areas (e.g., tectonic uplift, climate), according to **Thorne and Swift (1991)**.

Shepard (1934) investigated the canyons off the coast of New England and noted that faulting may have caused them. If this is the case, the canyons would have straight walls and the trough shapes typical of fault troughs.

MATERIALS AND METHODS

One of the Red Sea's branches, the Gulf of Aqaba, has a trend of N30°E to N-S (Fig. 1). It is the southern end of the Dead Sea rift, which is 1100 kilometers long **(Garfunkel, 1970)**. The Red Sea, where seafloor spreading takes place, and the Zagros zone of continental collision are connected by the Dead Sea rift, a type of transform plate boundary. According to **Freund and Garfunkel (1976)**, the first stage of the slip movement along the Dead Sea started in the Late Miocene or the Pliocene, while the second stage started in the Early Miocene or earlier.

The Late Tertiary and Quaternary have mostly shaped the current tectonic layout of the Dead Sea rift and its environs **(Eyal *et al.*, 1981)**.

According to **Ben-Avraham *et al.*, (1979)**, small fans at the mouths of short wadis on the western shore of the Gulf of Aqaba have steep slopes (up to 10° to 15°) and are made up primarily of large-sized particles, with boulders 1 m and larger predominating in a matrix of cobbles and pebbles and very little sand. Large fans that form on their own or anastomose at the mouths of multiple wadis contain fine-grained particles and mild slopes (1° to 2°); sand grains and layers of sand are more prevalent in the gravels. Additionally, they noted that the high-quality continuous seismic profiles in the Gulf of Aqaba under study appear to be exceedingly complex, which reflects the region's intense tectonic processes.

The multibeam echosounder HYDROSWEEP on the R/V METEOR was frequently used during the cruise. With a path width that is twice the depth of the water, the hull-mounted device, which sounds 59 pre-formed beams over a 90-degree opening angle, provides a topological image of the ocean floor. The system operates at a frequency of 15.5 kHz.

Bathymetric data was processed using MultiBeam, a free program **(Caress and Chayes, 1996)**. In particular, the zapping of outside beams and the detection and flagging of artifacts were made possible by the employment of automatic tools and an interactive editor. The depth values were reconstructed utilizing full ray tracing across a water velocity profile from the Leviticus database. The data were gridded using the GMT program, and contour plots were then displayed **(Wessel and Smith, 1998).** The multi-channel seismic reflection profiles were collected using a 390 m long, 24-channel streamer (Fig. 2). The seismic acquisition equipment used on cruise M44/3 in this area was based on a 300 m active streamer with 24 channels and a recorded midpoint distance of 12.5 m. Additionally, two hydrophone groups at a 0.32-meter distance were chosen. Seismic imaging of sedimentary strata using a source of 2 x 0.41 L and signal energy up to 350 Hz is possible.

Editing, CDP sorting, velocity analysis, normal move-out correction, CDP stacking, time-variant filtering, and migration from the finite difference wave equation make up the entire process. For interpretation, migrating profiles were used.

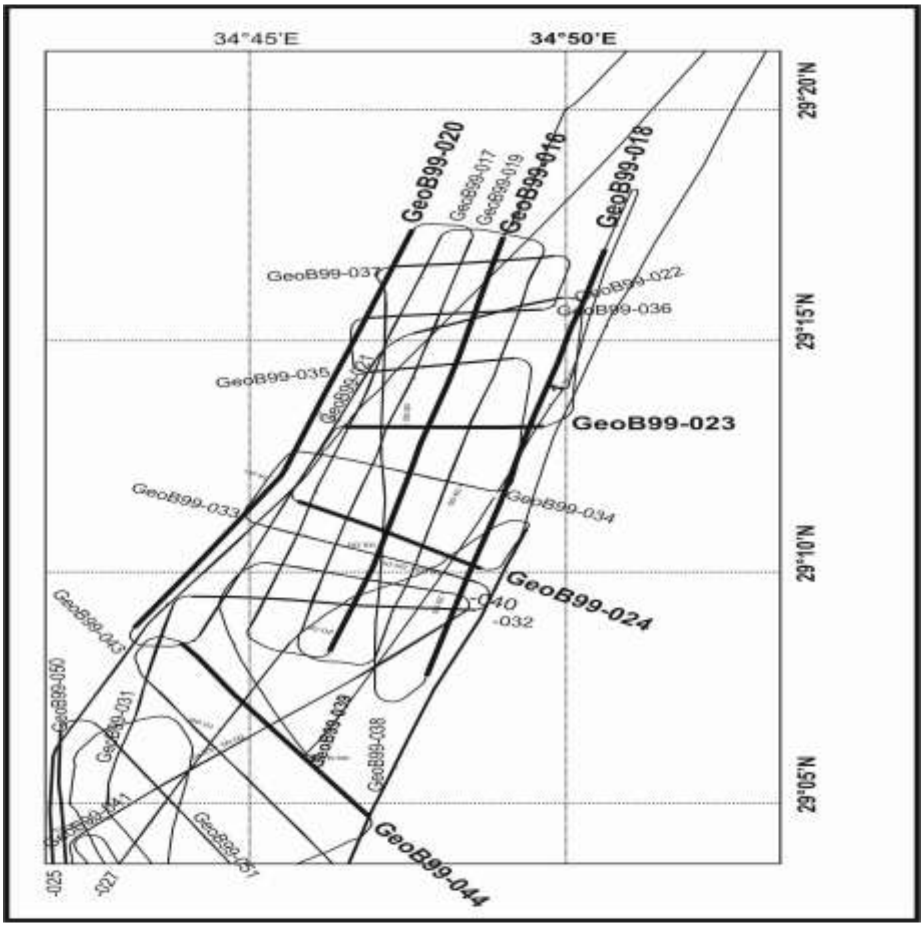

Fig. 2: Base map for the "Ras El Burka" survey area. Six selected multichannel seismic profiles are displayed with bold lines and labels (parallel and cross to the Gulf of Aqaba shore).

RESULTS AND DISCUSSIONS

1. Bathymetric Study of Ras El Burka

In a 20 km by 7 km stretch of the Wadi El Mahash El Asfal, bathymetric data were gathered. Except for a 2–6 km broad stripe close to the shore (Fig. 2a), where measurements could not be made, this area encompasses the entirety of the submarine prolongation of the Ras El Burka alluvial fan **(Salem, 2003)**. The surveyed region can be separated into a slope and a basin component, with water depths ranging from 100 to 950 m.

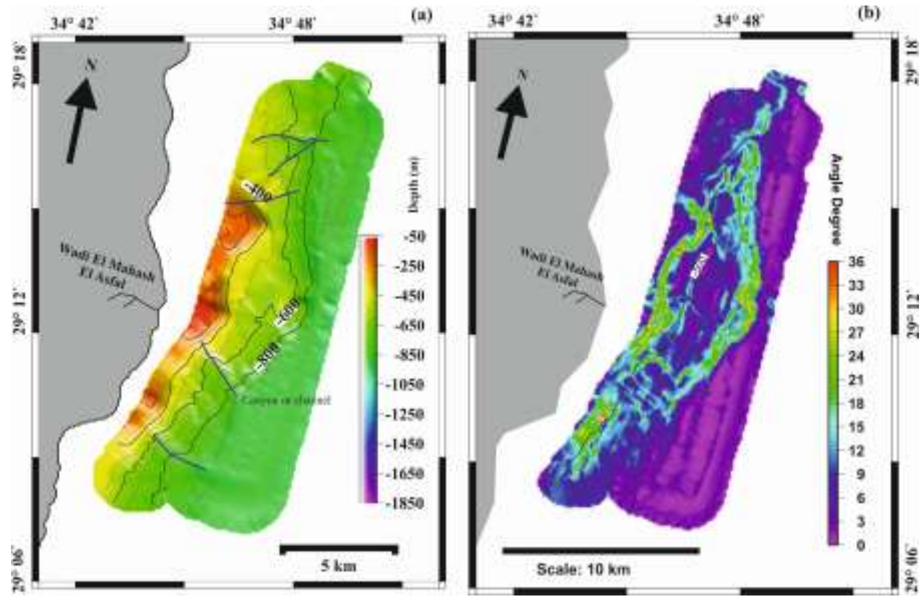

Fig. 3: (a) Bathymetric map of the Ras El Burka submarine prolongation alluvial fan (modified after **Salem, 2003**). (b) Slope angle map of the Ras El Burka submarine prolongation alluvial fan (modified after **Salem, 2003**).

The slope region stretches from the coast to a depth of 900 meters or so. It is distinguished by a rugged topography with significant slope gradients, averaging 4° with maximum values >20° (Fig. 2b). Near the coast, three morphological highs were found. The two smaller ones are about 5 kilometers to the North and South of the larger one, which is off the Wadi El Mahash El Asfal's mouth. For water depths between 100 and 400 m, the slope gradient steepens to >15° seaward of these highs. In the northern portion of the survey region, this change in morphology is not apparent, however, bathymetric coverage is lacking near the coast. While it is narrower to the South and North, the slope gradient continues to decline further down in an area up to 3 km wide of the Wadi itself. In this location, water depths range from 400 to 700 m, and slope angles are typically less than 4°. Fewer canyons in this location are locally connected with steeper slopes. A second significant change in morphology can be seen about 6 km away from the coast. For water depths between 700 and 900 m, slope gradients become >15° steep. Off the Wadi's mouth, this morphological step is the steepest.

In the northern part, a distinct step is also discernible, but in the southern part, it is absent. In the southern region, slope gradients in waters between 700 and 900 m deep are often less than 10°. The slope region is divided by a few short, straight gorges that run from the shore to 900 meters of water depth. The canyons (Fig. 2a) can be up to 1.5 km broad and 100 m deep. The sea bottom in the basin area is comparatively flat, with water depths of about 950 m.

2. Ras El Burka high-resolution multi-channel seismic reflection data

Multichannel, High-resolution seismic reflection studies of parallel (Figs. 4, 5, and 6) and perpendicular (Fig. 7, 8, and 9) seismic profiles are frequently preferable because they provide the shape of the canyons, their structural features, and the distribution of the seismic facies in the fan. Generally, seismic reflections are chaotic, patchy, frequently undulating, discontinuous, and uneven. A few Local minor unconformities are shown in some places. Submarine canyons (typically V-shaped cross sections) that narrow and deepen with increasing sea depth (i.e., approaching the basin) cut across the seismic profiles.

The middle portion of the seismic lines GeoB99-020, GeoB99-016, and GeoB99-018 (Fig.s. 4, 5, and 6, respectively) display the cone of the Ras El Burka submarine prolongation fan. A few canyons (Fig. 4) divide the Ras El Burka fan’s surface. The fan's canyons appear to be partially directed by faults. The canyons' largest width is one kilometer, and their maximum depth is 130 m. The canyons, which are primarily V-shaped and diminish in number and depth from the shore towards the basin of deposition, are seen in these figures. On the cone's western side slope, several slumps and/or slides with chaotic low (transparent) amplitude seismic internal reflectors were created (Fig. 9). Be aware that from the shore to the depth of the gulf, the size of the cone and the number of canyons diminish, especially from seismic lines parallel to the coast.

In the middle of the lines (fan cone) and toward the western side (shallow water), these multichannel seismic lines exhibit several discontinuous, frequently undulating, subparallel to parallel, moderate to high-amplitude reflectors (Figs. 7, 8, and 9). These reflectors then change to chaotic moderate to high-amplitude seismic reflectors. Graben fault-connected canyons (channels) are totally or partially filled with chaotic, high-amplitude internal reflectors.

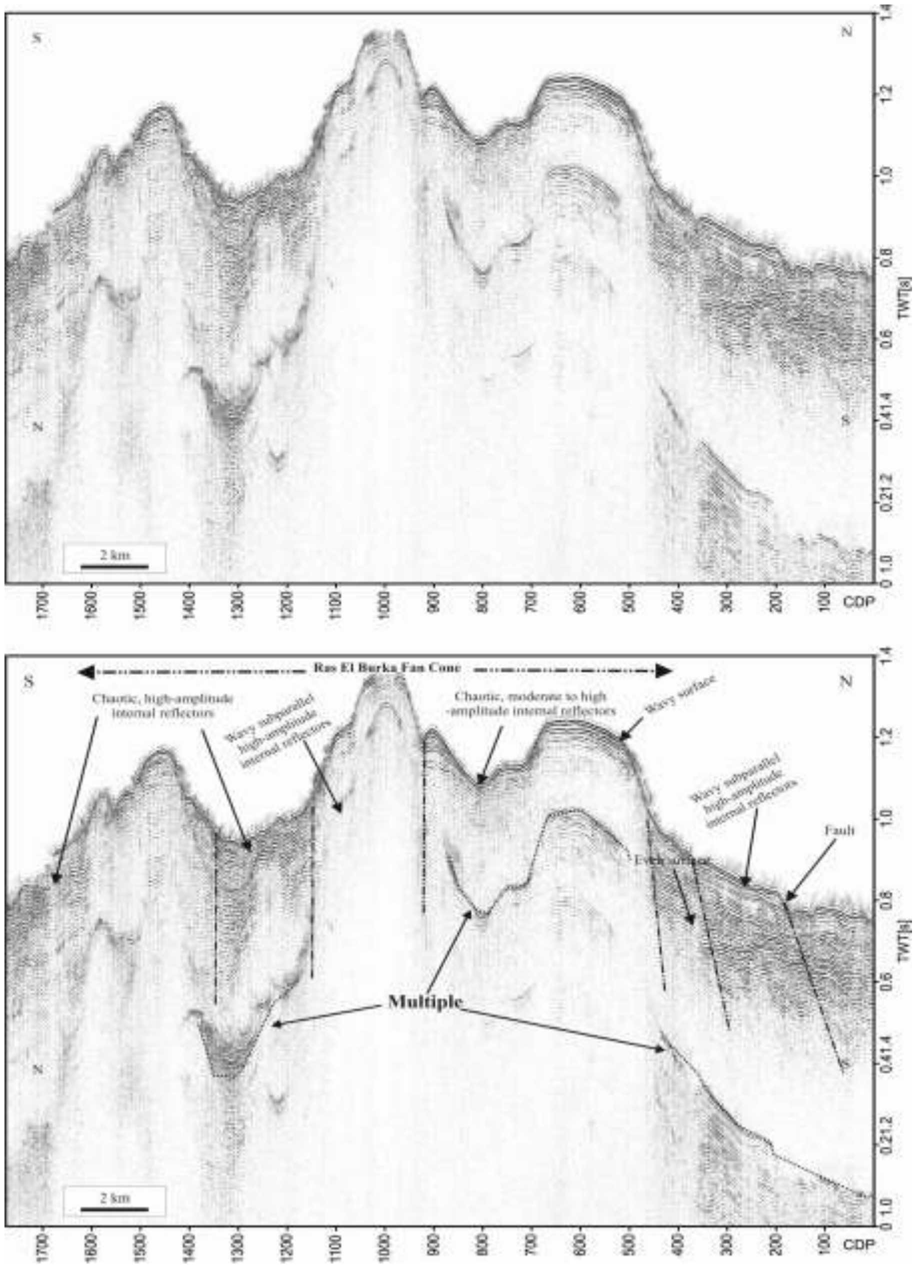

Fig. 4: Seismic interpretation of the GI-Gun Line GeoB99-020. According to Fig. 2, the profile's location is along the gulf's coast. In the middle of the line, canyons or channels dissect the cone of the fan.

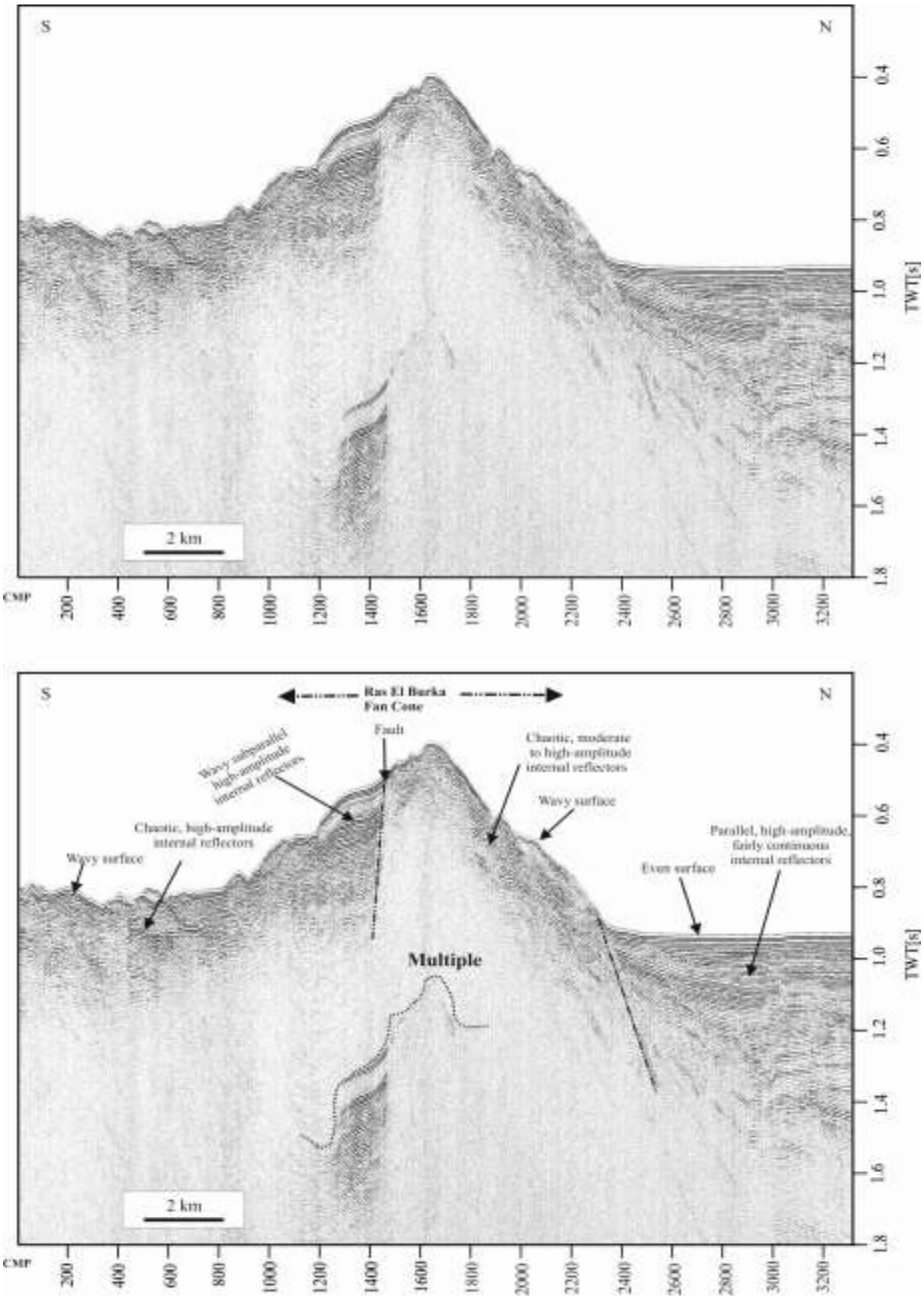

Fig. 5: GeoB99-016 GI-Gun Line seismic interpretation. Fig. 2 depicts the profile's location. In the middle of the line, the fan's cone can be seen.

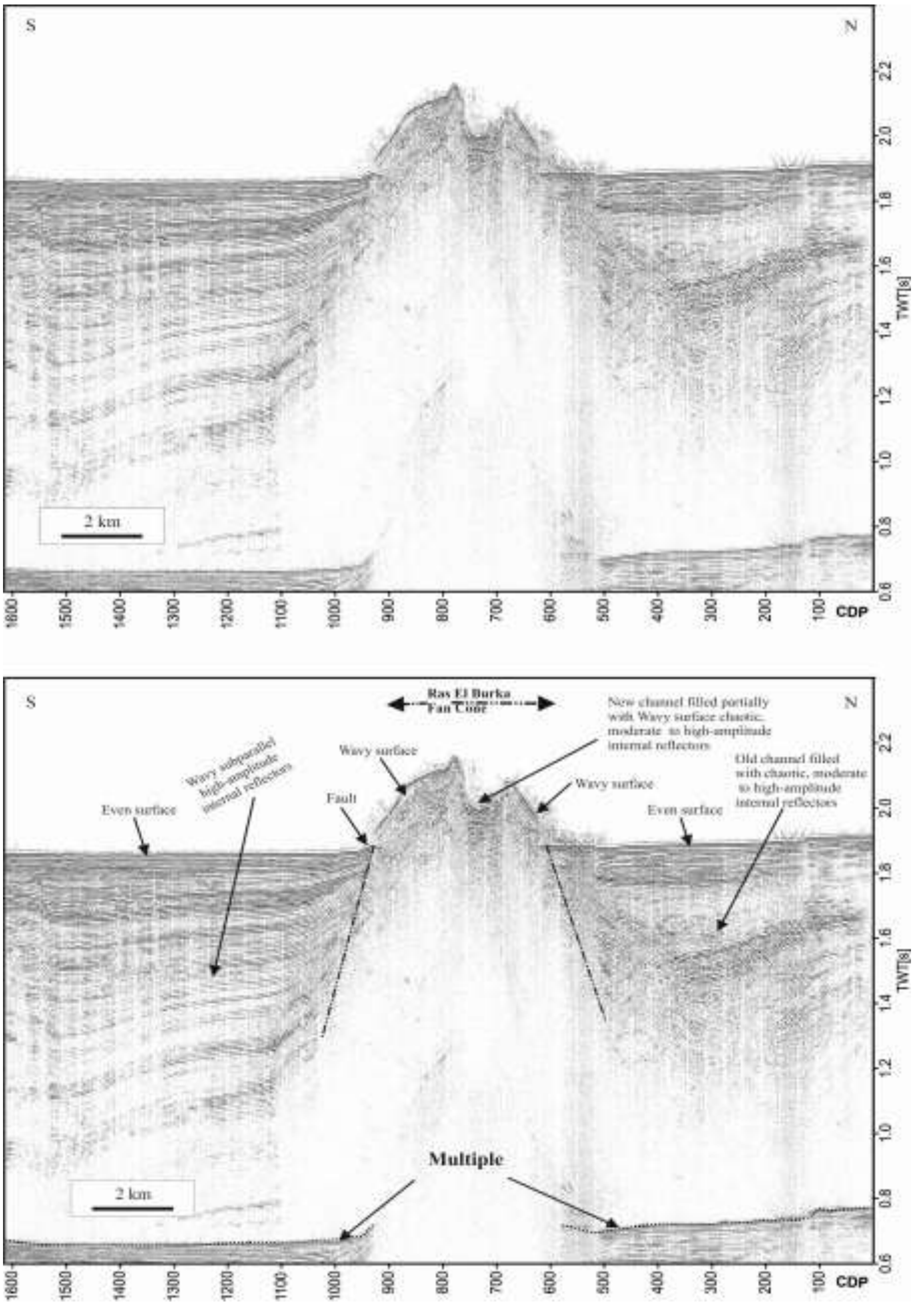

Fig. 6: Seismic interpretation of Line GeoB99-018, GI-Gun. The Location of the profile is shown in Fig. 2. One canyon dissects the cone of the fan, which is in the middle of the line.

Seismic line GeoB99-020 (Fig. 4) is mainly characterized by internal reflections of moderate to high amplitude, which are chaotic and hummocky. Chaotic low-amplitude seismic facies are generally found at the base of the slope of the upper surface of this seismic line. The upper surface of this line is also dissected with a few shallow canyons filled with chaotic deposits.

All around the fan, but especially along the coast and in regions with steep slopes, are the chaotic facies. These deposits, which include slides, slumps, and debris flows, are what we interpret as slope failure deposits.

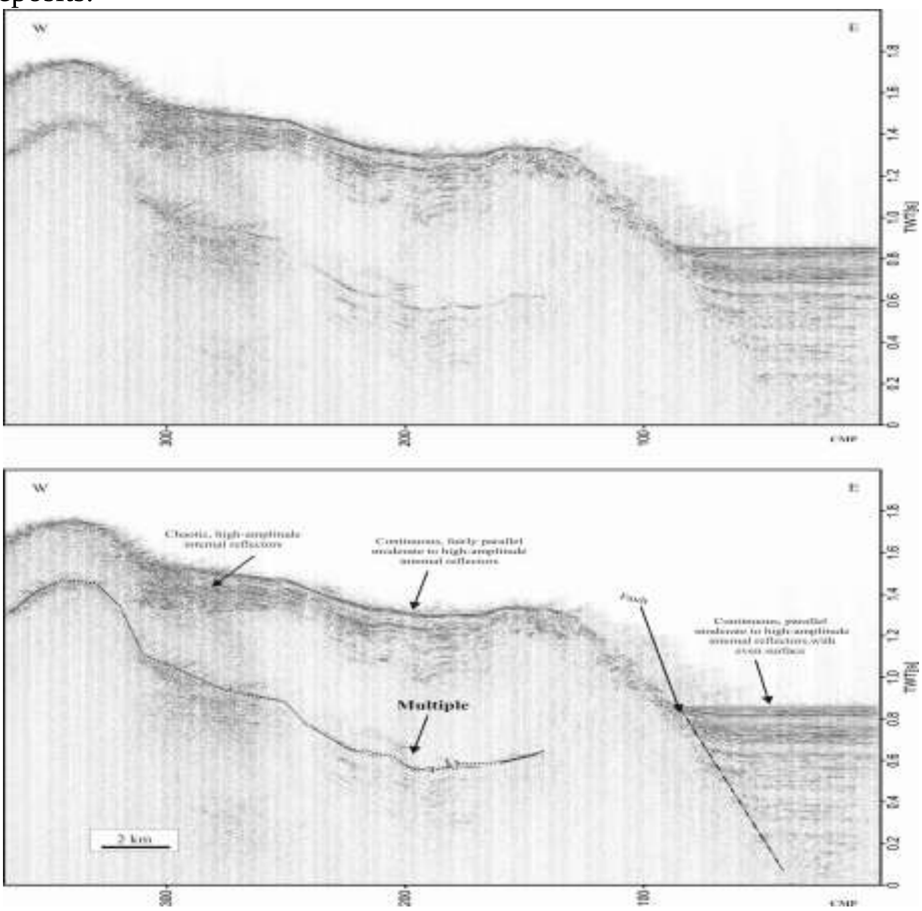

Fig. 7: GeoB99-023, GI-Gun, seismic interpretation. Fig. 2 depicts the location of the line. Be aware that the seismic facies significantly change from the shore (in the west) to the Gulf's depths (in the east).

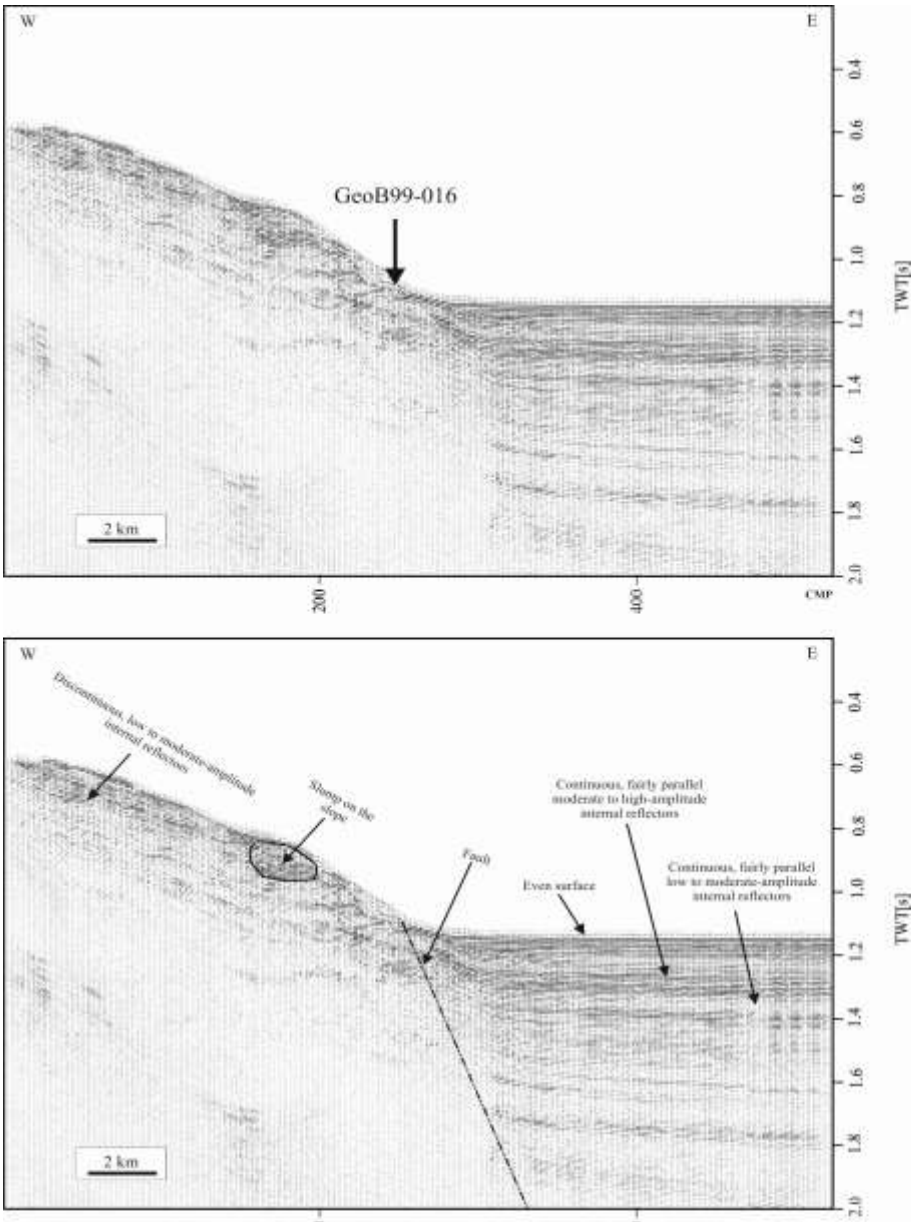

Fig. 8: GeoB99-024, GI-Gun, seismic interpretation. Fig. 2 depicts the location of the line. Note that the seismic facies close to the coast (West) and the seismic facies farther into the gulf (East) can be contrasted (chaotic low-amplitude seismic facies with slumps (W) and subparallel to parallel and continuous internal reflectors (E).

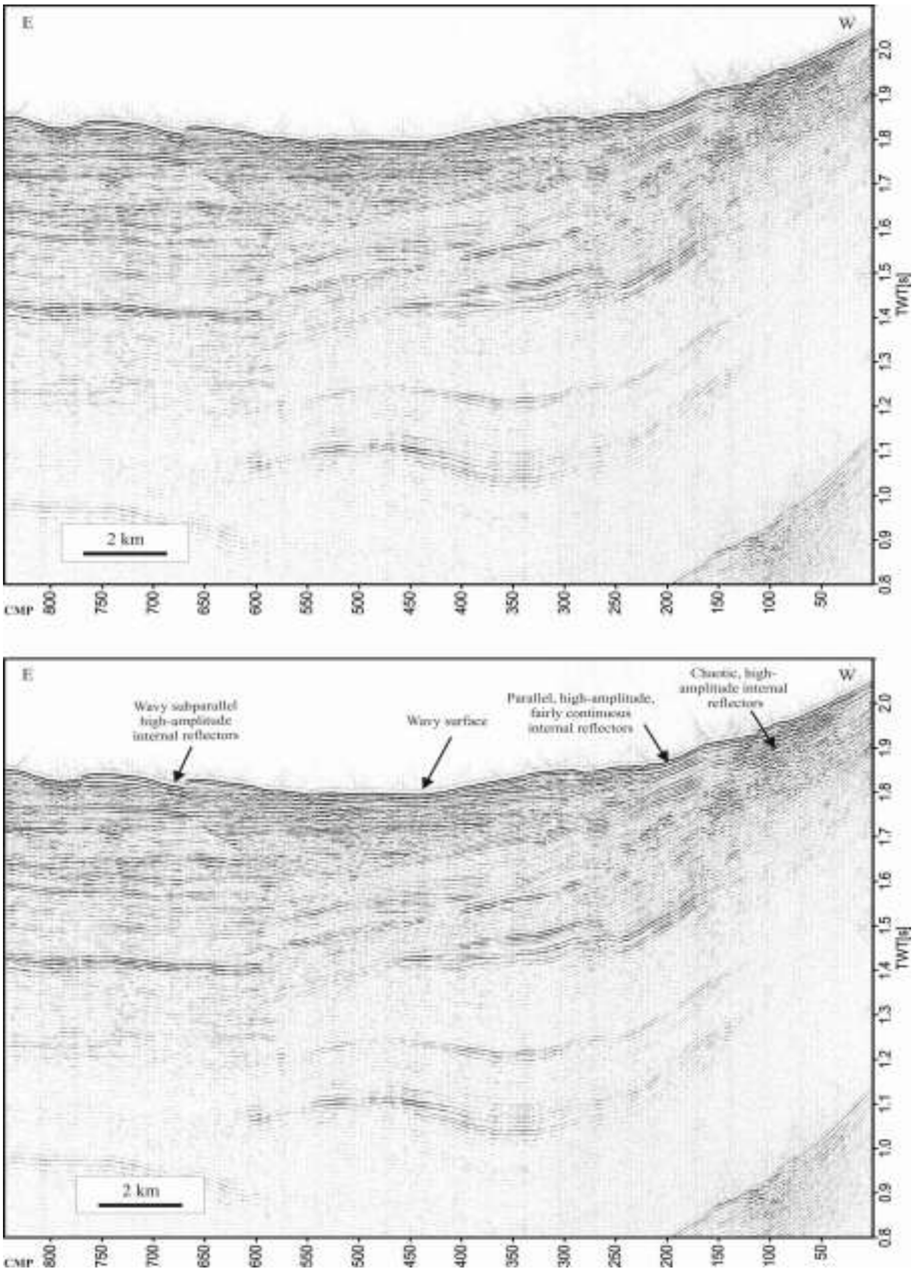

Fig. 9: GeoB99-044 Line GeoB99 seismic interpretation for GI-Gun. Fig. 2 depicts the location of the line. This line shows the fan's deepest fan margin toward the basin. The seismic facies are mostly subparallel to parallel, with a moderate to high amplitude.

The Ras El Burka submarine fan displays six seismic facies (Table 1) that were previously mentioned based on the seismic profile descriptions. The predominant seismic facies are irregular, subparallel, continuous to discontinuous, moderate to high reflection toward the coast, and discontinuous parallel to subparallel, moderate to high reflection toward the gulf basin. Additionally, the seismic facies are randomly distributed both laterally and vertically within the fan. The predominant seismic facies are (1) subparallel to parallel and continuous reflectors, which typically represent well-sorted, layered sediment. It is composed of silt or sand that was deposited, probably on the continental shelf, and (2) chaotic or/and wavy reflectors, which probably represent sediment made of poorly sorted grains that were deposited in a higher flow regime with deltaic or submarine fan sedimentation **(Mitchum *et al.*, 1977).**

All around the fan, but especially along the coast and in regions with steep slopes, are the chaotic facies. These deposits, which include slides, slumps, and debris flows, are what we interpret as slope failure deposits.

Table 1. Classification of sediment seismic facies including a tentative interpretation.

Reflection amplitude	Reflection geometry and continuity	Type of interpreted sediment
Medium (moderate) to high	Discontinuous subparallel to parallel	Sands and coarse-grained turbidites of slope and canyon-related environments
Medium (moderate) to high	Internal chaotic, subparallel, and discontinuous	Gravel-to-sand sizes
Medium (moderate) to high	Internally hummocky with discontinuous, strongly hyperbolic diffraction	Gravel-to-sand sizes
Medium (moderate) to high	Subparallel to discontinuous chaotic lenses	Gravel-to-sand sizes
Medium (moderate) to high	Continuous to discontinuous, irregular, and subparallel	Gravel-to-sand sizes
Low	Subparallel and/or structureless, discontinuous internal reflections	Mud and clay deposits or silty clay

According to the interpretation of these seismic facies, they are composed of sediments with a coarse grain size. The Gulf of Aqaba was deformed over several structural epochs by tectonic action. Syntectonic motions were responsible for the change in deposition and facies thickness. As can be seen in Figs. 7, 8, and 9, the seismic facies are likewise deformed most strongly towards the direction of the basin (NE).

Slope failures (slope instability) are the cause of the profusion of slide and slump masses (chaotic, low-amplitude reflection seismic facies) on the slope of several sections along the seismic profile in the region. Thus, slope instabilities may be caused by an increase in stress, a decrease in sediment strength, or both **(Coleman and Prior, 1988)**. According to **Duperret *et al.*, (1995)**, the two main causes typically cited for slope instabilities are (1) an increase in downslope stress caused by an external load or basal unload. When the slope angle steepens because of tectonic activity or rapid sedimentation, external stress is generated. Additionally, earthquakes might directly hit the ocean floor. Subduction of a graben, or negative oceanic asperity, may cause a basal unload. (2) A high pore water pressure level lowers the effective normal stress on the failure plane and, as a result, lowers the shearing resistance. The result is a direct decrease in stability. High rates of sedimentation, earthquakes, and accumulations of allochthonous fluids can all contribute to excessive pore pressure. Turbidite and debrite sediments are deformed as a result of seismic shaking, which is typically efficient in liquefying sediments in semi-enclosed topographic depressions **(Syvitski *et al.*, 1987; Mulder & Cochonat, 1996; Syvitski and Schafer, 1996)**.

The seismic profiles examined in this fan primarily exhibit chaotic facies, which are represented by discontinuous, disorganized, and hummocky reflections. It is interpreted as fan facies. The chaotic reflections resemble the characteristics of channel-fill deposits and slope failure flow **(Shanmugam and Moiola, 1988; Weimer, 1991; Ercilla *et al.*, 1998)**. These deposits likely feature discontinuous, truncated, or faulted strata and were generated in a high-energy depositional environment, according to the chaotic internal reflection configuration **(Seramur *et al.*, 1997)**. According to **Piper *et al.*, (1985) and Carlson (1989)**. The internal reflection configuration of the chaotic seismic facies in the area is like the seismic signature of slumps, slides, and debris flow deposits **(Piper *et al.*, 1985; Carlson, 1989).** The internal reflection configuration of the chaotic seismic facies in the region resembles the seismic signature of deposits from slumps, slides, and debris flows. The seismic profiles' irregular reflections may have been caused in part by an accumulation of boulders or gravel. In various fan deposits in subaqueous habitats, channelized sediment and gravity flow deposits are documented

(Rust and Romanelli, 1975; Rust, 1988, Stewart, 1990). According to **Piper (2001)**, rotational slumps and debris flows caused internal discontinuous reflections and wavy in another location.

3. Development of the Ras El Burka fan

The Ras El Burka submarine fan's growth trend resembles those of the other fans in the Gulf of Aqaba. The important events throughout the evolution of this fan are very well understood from the high-resolution multi-channel seismic profiles analysis in addition to the bathymetric map that was created for the fan. Beginning in the Pleistocene, flows from the Sinai Peninsula's basement, and sedimentary strata continue seaward through Wadi El Mahash El Asfal during the occasional wet season. Turbidite deposits supplied by the active canyons, which are thought to be the major conduits of turbidite sediments, followed these flash flood deposits, which were transported by the wadi. The morphology of the substrate, faulting activity, catastrophic pulses (earthquakes), and the primary sedimentologic processes all contribute to changes in the seismic facies (i.e., changes in the sediments), the presence of slumping and/or slides, and pelagic or hemipelagic sedimentation. The sediments in the fan often have coarse grains that get smaller as they get closer to the basin.

They also offered a scenario and a rough sketch for the genesis and evolution of these canyons, which went like this: (1) faulting activity (graben faults) produced proto canyons that later served as a route for the wadi sediments formed during periodic severe rains. (2) Submarine processes become crucial for ongoing erosion (canyon incision and enlargement). (3) The still-active faults and reflooding are what caused the steep canyon walls (V-shaped cross-section). (4) Steep slopes lead to slides and landslides, while earthquake shocks cause canyons to spread and take on a U-shaped cross-section.

CONCLUSIONS

The following has been discovered by analysis of the bathymetric and high-resolution seismic lines that span the alluvial fan known as Ras El Burka prolongation, which was constructed on the western shore of the Gulf of Aqaba:

(1) According to seismic facies, the sediments of the fan are primarily composed of gravels or coarse sand and sand with intercalation of fine grain sediments that were produced by the erosion of the nearby hills and mountains (the mountains on the Sinai Peninsula).

(2) Numerous canyons cut into the fan. A noticeable fault pattern seen in the fan can be used to explain the formation of these canyons. The topography of the canyons and the discontinuity of the seismic reflectors attest to faulting's significant involvement in controlling the position of canyons.

(3) A small number of the fan's canyons exhibit shallower (130 m deep) valleys with a V-shape contour.

(4) The fan is covered in numerous slumps and slides, particularly in and around canyons, steep slopes, and scarp faults.

(5) The fan contains finer sediments toward the deep sea, but the sediment composition as inferred from seismic facies (belongs to a coarse-grained, sand-rich turbidite system) is closer to the coast.

(6) The Ras El Burka undersea fans have a complicated growth pattern. Large volumes of silt from the basement and sedimentary rocks of the Sinai Peninsula are transported into the Gulf of Aqaba by flash floods that form in onshore wadis during the infrequent wet seasons. The distribution of these sediments is greatly influenced by the submarine processes and tectonic activity in the Gulf of Aqaba after these materials have been deposited. Also take note of how the size of the cone and the number of canyons decrease from the shore to the deep of the gulf, as is evident from the seismic lines running parallel to the coast.

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تحليل البيانات الباثيمترية والبيانات السيزمية الإنعكاسية متعددة القنوات لامتداد مروحة رأس البركة التحت مائية، خليج العقبة، مصر

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عند مدخل وادي المحاش الأسفل تم تكوين المروحة الطميية والتي تسمي رأس البركة والتي تمتد تحت سطح الماء على الجانب الغربي من خليج العقبة. في هذا البحث قمت بمحاولة شرح نمط نمو المروحة وترسيبها وبنيتها، إلي جانب وصف سطحها المورفولوجي.

وقد حصلت علي البيانات الباثيمترية والسيزمية والتي أستخدمت في الدراسة الحالية، من المسوحات الجيوفيزيائية التي أجريت في شمال البحر الأحمر وخليج العقبة خلال الرحلة البحرية M44/3 في عام 1999 والتي كنت أحد أعضائها.

تكونت رأس البركة من الرواسب التي أنتجت من تعرض تلال وجبال شبه جزيرة سيناء للتآكل (التعرية) أثناء هطول الأمطار عليها، ثم نقل الرواسب إلى خليج العقبة عبر وادي المحاش الأسفل. وفي تلك الدراسة تم تفسير السحنات الرسوبية داخل مروحة رأس البركة باستخدام مقاطع سيزمية متعددة القنوات عالية الدقة، والتي كشفت عن وجود سحنات سيزمية متعددة. ولقد أظهرت هذه السحنات السيزمية السائدة انعكاسات ذات سعة متوسطة إلى عالية، والتي يُفهم أنها عبارة عن حصى لرواسب رملية. وبذلك صنفت رأس البركة علي أنها تتبع نظام المراوح البحرية الغنية بالحبيبات الكبيرة والرمال. ونظرًا لأنه لا تزال هناك صدوع نشطة ومنحدرات شديدة الانحدار فنجد كثيرا من الإنزلاقات الرسوبية متواجدة على المنحدر الحاد، وجدران الأخاديد، ومنحدرات الصدع للمروحة. وأيضا استخلصت في هذه الدراسة بأن التفاعل بين تدفق الرواسب، والتكتونية، والظروف المناخية كان له تأثير كبير في تحديد أنماط الترسيب في المروحة.