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A CREVASSE SPLAY INDUCED AVULSION ON THE CEYHAN DELTA

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Abstract
As a result of flood occurred on the delta of Ceyhan River in 1935, a crevasse splay of 25.8 km² (7.5 km wide, 4.4 km long) occurred and Ceyhan River formed a new channel of 9.1 km on this new splay directing the water at the southern edge of the delta. This crevasse splay converted 17.7 km² (57.3% of the whole lake) of Lake Akyayan of 30.9 km² into land. The development of crevasse splay finalized substantially until 1970s and Ceyhan River started to discharge into the Mediterranean Sea at the southern edge of the delta via one single channel on the splay.
Keywords: Crevasse splay, avulsion, Ceyhan Delta, Akyayan Lake, Akyayan Lake Splay.

1.Introduction

Avulsions play the main role for lateral aggradation in deltas. Studies on avulsions on modern rivers and crevasse splays due to avulsions have increased since 1980's (Obrien and Wells, 1986; Smith *et al*. 1989, Smith *et al*. 1998, Farrell, 1987;2001; Smith and Perez Arlucea, 1994; Törnqvist, 1994; Perez Arlucea and Smith, 1999; Bristow *et al*. 1999; Ethridge *et al*. 1999; Aslan and Autin, 1999; Aslan and Blum, 1999; Stouthamer and Berendsen, 2000;2007; Slingerland and Smith, 1998;2004;). Crevasse channels may carry coarse sediment to the flood plains depending on the depth of crevasses on levees. Suspended sediment crossing over river levees during floods may form fine-grained layers in floodplains whereas crevasse splay channels provide the storage of coarse-grained sediment in the floodplains (Allen, 1964). Avulsions provide the storage of the whole sediment, including the bed load of the river, in another part of the delta.

While main channel may change and start flowing through a widening crevasse channel in time (e.g. Bristow *et al*. 1999), sometimes a former river bed could be a main channel again so that new crevasse splays may occur on both side of the channel due to excess water and sediment beyond carrying capacity of the new channel (e.g. Smith *et al*. 1989).

Çukurova Delta in the south of Adana is the biggest of delta of Turkey and it was formed by Seyhan, Ceyhan and Tarsus rivers. Ceyhan Delta, the eastern part of the Çukurova delta, is separated from the main delta by Karataş threshold along northeast-southwest direction and covers an area of 214 km². Ağyatan lagoon is located on the south, a bigger lagoon that is called Eşemen and Avcıali lakes on the east and towards Yumurtalık lagoons (Ömer, Darboğaz and Arapboğaz lakes) are located in the north of Ceyhan Delta (Fig. 1). There is a former river bed still traceable on the west of today's river bed and another former river bed that lies towards northeast is pronounced and abandoned in 1935. Eastern part of Ceyhan Delta was designated as first degree natural site in 1993, nature reserve area in 1994 and Ramsar site in 2005.

Ceyhan River plays a very important role for the evolution of Çukurova delta where sediments have been brought to Mediterranean by Seyhan, Ceyhan and Tarsus Rivers since the early Pleistocene and formed Ceyhan delta with its own sediments only in the east of Karataş threshold (Erinç 1953).

Ceyhan Delta is divided in four parts by Erinç (1953) considering today's and former river beds. First delta is formed in the east of Bebeli village, next Ceyhan river heads south and flows into Hurmabogazi, and then turns northeast and heads towards Yumurtalik bay so that the delta expanded that direction. Due to the flood in 1935, the river turns south again and flows into Hurmabogazi.

Russell (1954) indicates that the river formed a new channel and a new delta lobe towards south in 1935 and drew a map of it (The channels developing on the crevasse splay in the map are matching with the aerial photos of 1948, but a line of swamp area left out of Akyayan lake is observed).

Erol (2003) maps the evolution of the delta in 10 phases using 1953 aerial photos of the delta. Last phase shows the extension of the delta towards Yumurtalik Bay and the deposits at the mouth of today's river bed. He has not given a certain time for the last change of river bed, but stated that the river started

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flowing into the sea today after this change. Besides he shows that this part of the delta was formed with sediments carried between 9th and 13th century.

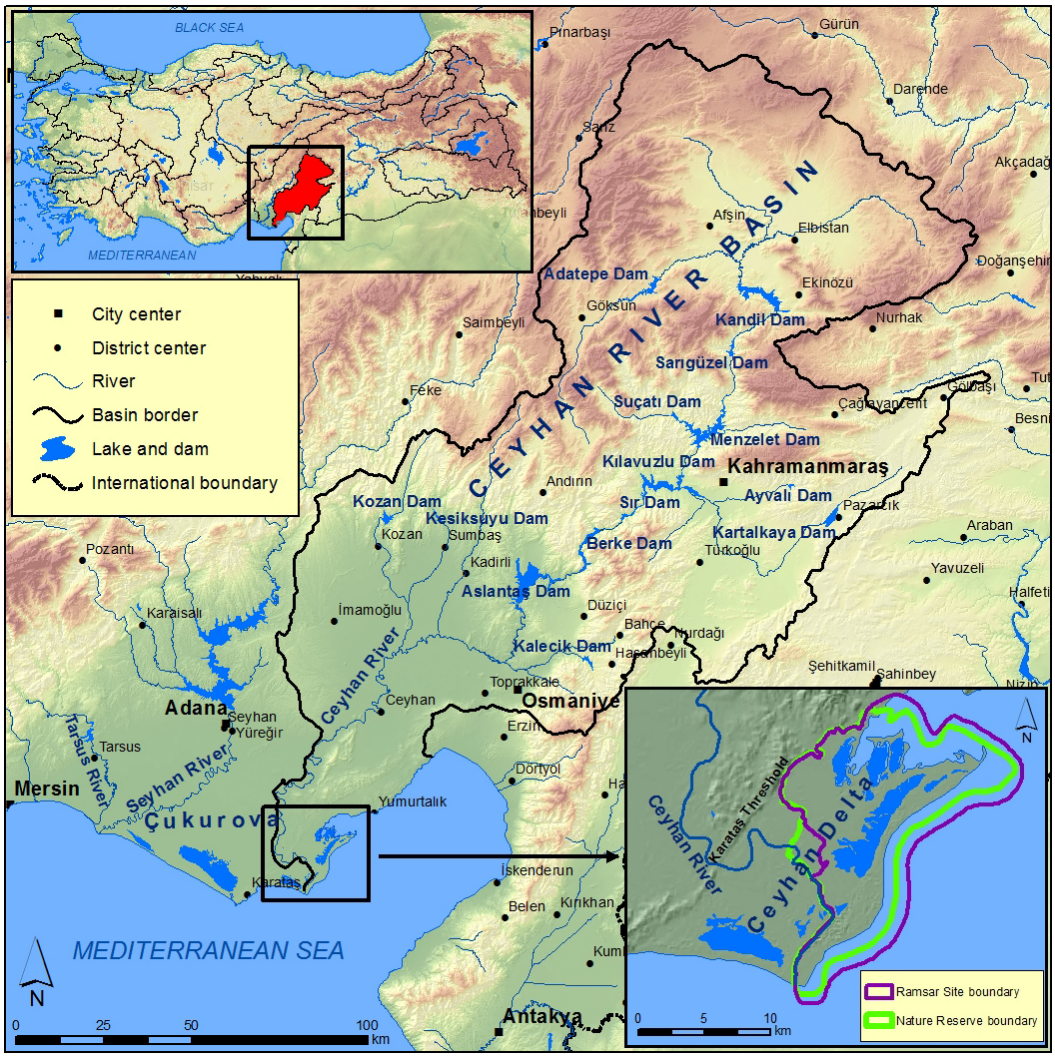

Fig. 1. Ceyhan River Basin and Ceyhan Delta

When we look at the 1:200.000 scaled topographic map drawn in 1916, the landscape is very different from today (Fig. 2a). The largest lake with an area of 30.9 km^2 was Lake Akyayan in Ceyhan Delta according to this map. The southwestern part of the lake is converted into land today and the current river bed of Ceyhan River flows here. Although modern maps with 1:100.000 and 1:25.000 scales became widespread and 1:200.000 scaled maps lost their importance, they were cited for small scaled wall maps of Turkey and Lake Akyayan had been shown with its former boundaries. Books on Turkey's Lakes also show Lake Akyayan with its former boundaries (İnandık, 1965, Hoşgören, 2010). The south of the remaining part of the lake today is shown as Lake Eşemen and north is shown as Lake Avcıali in modern topographic maps.

This study aims to reveal the development of the Akyayan Lake Splay and the avulsion of Ceyhan River.

2.Materials and Methods

The map and aerial photos that were used on this study were obtained from General Command of Mapping Archive. 1 / 200.000 scaled topographic map drawn in 1916, aerial photos of 1948, 1953, 1973, 1994, 2009 were used for revealing the development of the crevasse splays of Ceyhan River. The map and aerial photos were rectified with Arcmap 10 software considering Universal Transverse Mercator projection according to zone 36 parameters. Fluvial forms and shorelines on maps and aerial photos were digitised manually in geographical information systems and their lengths and sizes were measured. The data for calculating the amount of flow and sediment were obtained from the gaging station that is located 20 km north of the delta. This data was used for the filling period of the cravasse splay in the lagoon.

3.Results

3.1. Ceyhan Delta Pre-Avulsion

The only source that shows how Ceyhan Delta looked like before 1935 flood is a 1:200.000 scaled topographic map dated 1916. The largest lagoon in this map is Lake Akyayan and covers an area of 30.9 km². The lagoon links to the sea at the southernmost edge. Just like today Lake Agyatan is located at southwest, the structure that is called Yumurtalik lagoons containing Omer, Darbogaz and Arapbogaz lakes (west to east direction) are located in are located at northeast. Ceyhan River turns east first and then makes a more than 90 degree turn to Lake Akyayan direction after Karataş threshold and joins Yumurtalik Gulf. There are seven sand dune extent on the northern coasts of Lake Akyayan. These extents are the remains of old crevasse channels and the most southern one probably prevented the spreading of the crevasse splay into the whole lake (Fig. 2a).

Former rived beds of Ceyhan river are very pronounced in the south of Lake Akyayan (Some of these river beds were not shown in 1916 map and added to Fig. 2a according to the aerial photos of 1948). In this part of Mediterranean Sea, the current direction is northeast so that the coastal barrier that lies southwest-northeast direction and forms Lake Akyayan is a result of sediment carried by the former rived bed of Ceyhan River.

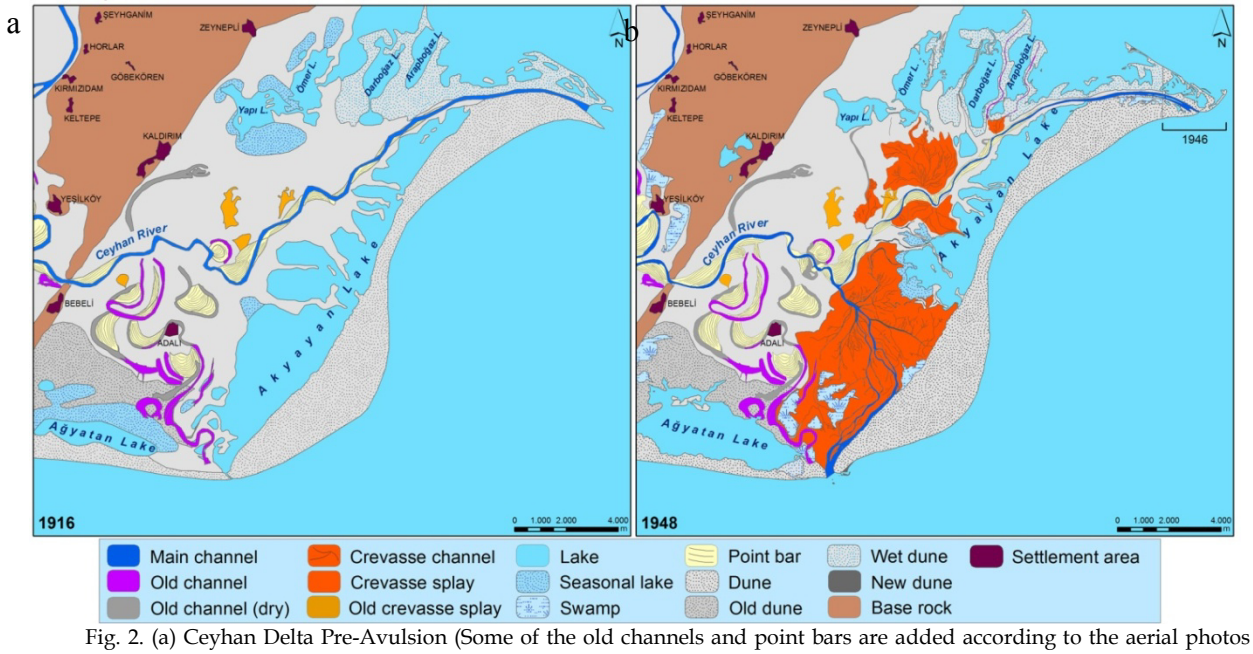

Fig. 2. (a) Ceyhan Delta Pre-Avulsion (Some of the old channels and point bars are added according to the aerial photos of 1948). (b) The view of Ceyhan Delta in 1948 (The aerial photo of the northeastern edge (former Ceyhan river mouth) of the delta is not available. A 1946 aerial photo taken by USA that is also used in master thesis of Bal (1984) is used for this section.)

3.2. Ceyhan Delta Post-Avulsion (1935-1984)

Flows were started to be measured at Ceyhan River in 1965 and there are no records prior. Thus the time when Ceyhan River turned south due to the change of river bed is considered as year 1935 as Erinç (1953) and Russell (1954) proposed. The oldest aerial photos (accessible to researchers) were taken in 1948 and it is seen that Ceyhan River changed its river bed and formed a 7.5 km crevasse splay in Lake Akyayan in the south. This deposit turned 17.7 km² (57.3% of whole lake area) of Lake Akyayan of 30.9 km² into the land. River spreads into two branches on this deposit and unites again right before joining the sea. Other branches that cause the spread of the splay are abandoned (Fig. 2b). There is a swamp area as two pieces left in the southern part of Lake Akyayan and it is seen that terminal-mouth bars belonging crevasse channels are developing on these swamps (Fig. 3).

First flow and sediment measurements were made in 1965 in Ceyhan River and the first big dam (Aslantas Dam) in the basin started operating in 1984. 19 years prior to the dam gives an idea about the flow and the amount of sediment that Ceyhan River carries under natural circumstances.

The average depth in the lagoons of Çukurova (Akyatan, Ağyatan and Lake Tuz) is around 80 cm (Yaşar et al., 1999). If the same amount of depth is taken for Lake Akyayan, 14.160.000 m³ of sediment is needed to cover an area of 17.7 km² of lake area of Akyayan. The amount of suspended sediment is 19795 tons/day (EİE, 2000) before dam constructions on Ceyhan River (1965-1984) so that it took around two years (715 days) to fill this part of the lake.

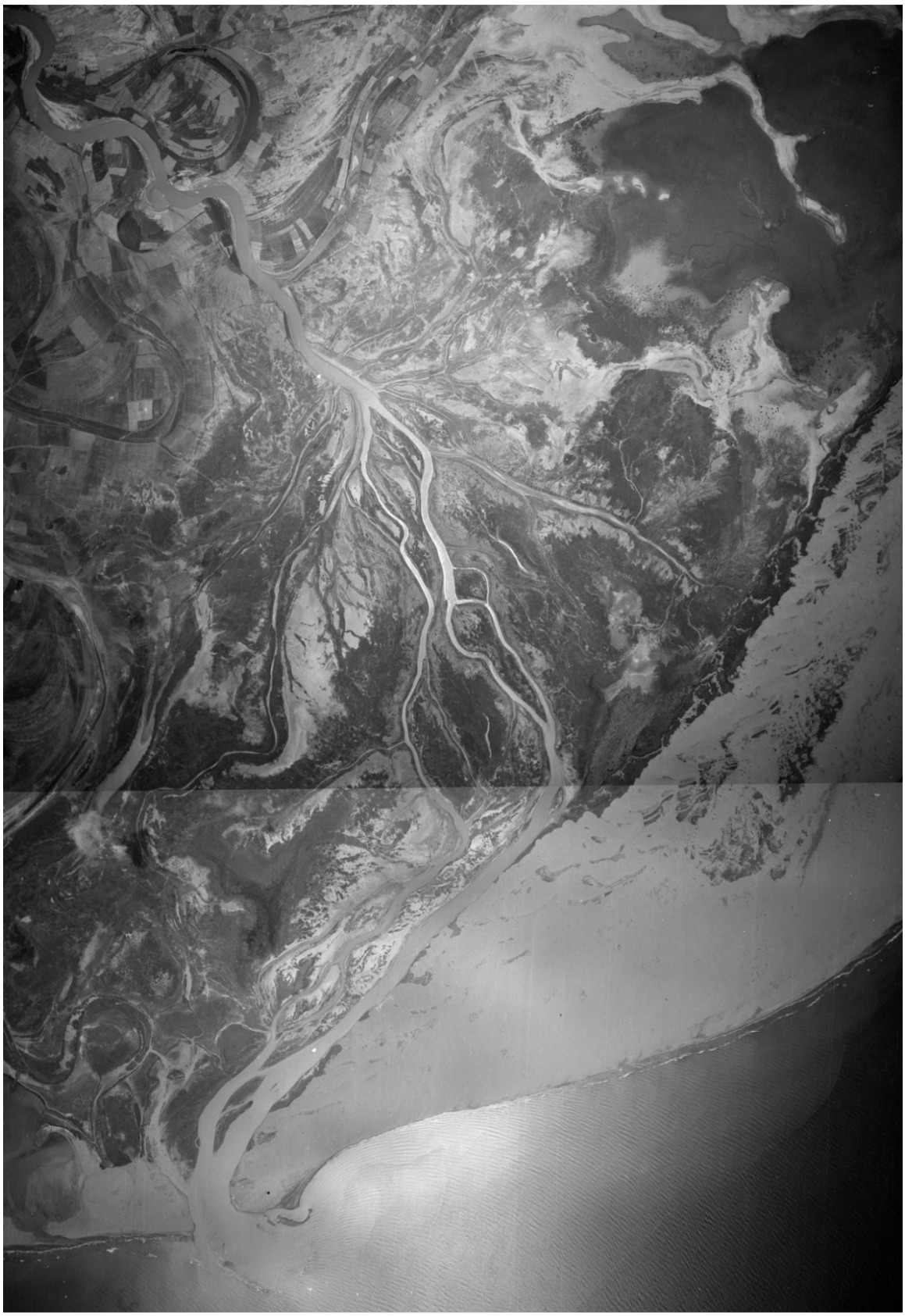

Fig. 3. Aerial photo of 1948 showing the crevasse splay and the formation of channels after the flood in 1935 (Source: General Command of Mapping Aerial Photo Archive).

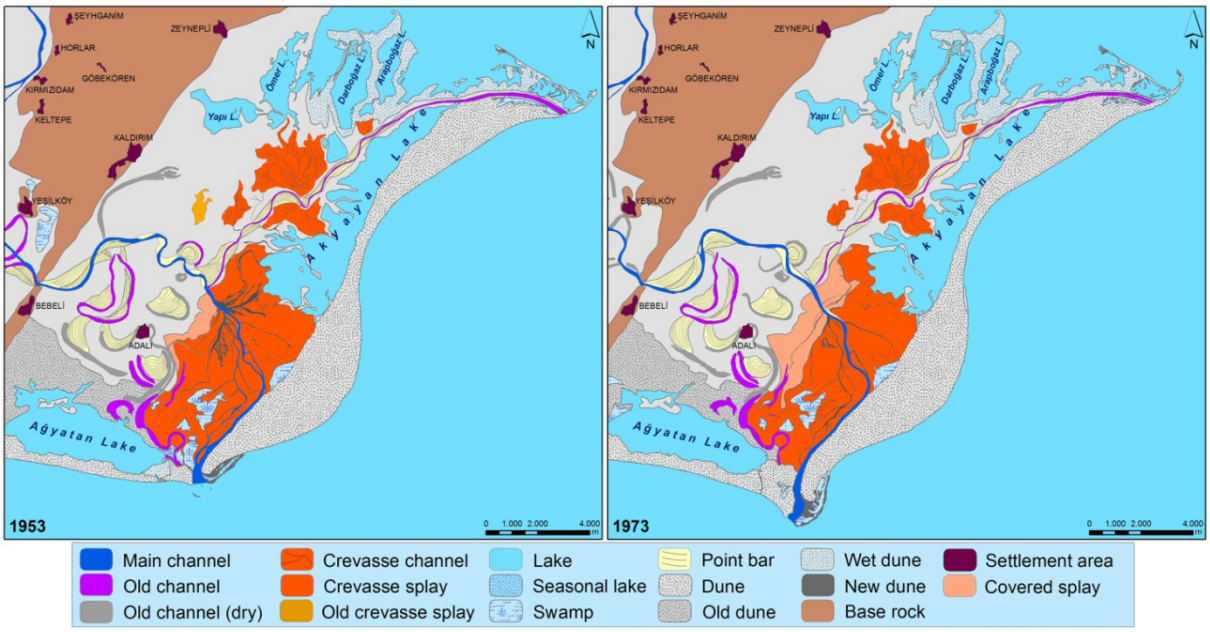

Fig. 4. (a) The view of Ceyhan Delta in 1953. (b) The view of Ceyhan Delta in 1973

3.3. Ceyhan Delta Post-Large Dams (1984-Present)

The first large dam constructed on Ceyhan River is Aslantaş Dam and started operating in 1984. After this dam, Menzelet Dam (in 1989), Sır Dam (in 1991), Berke Dam (in 1999), Suçatı Dam (in 2000), Kılavuzlu Dam (in 2001), Ayvalı Dam (in 2006), Kandil, Sarıgüzel and Adatepe dams (in 2013) started operating. In this period of time agricultural activities increased in the delta and a large portion of crevasse splay are converted into agricultural fields. Due to intensive agricultural activity, point bars were not visible anymore in 2009. Besides drainage channel that was constructed nearby Zeynepli village in the north of the delta caused the formation of an alluvial fan in the north of Yapı Lake and this fan narrowed Yapı Lake from the north. It became a seasonal lake after its link to the sea was cut (Fig. 5).

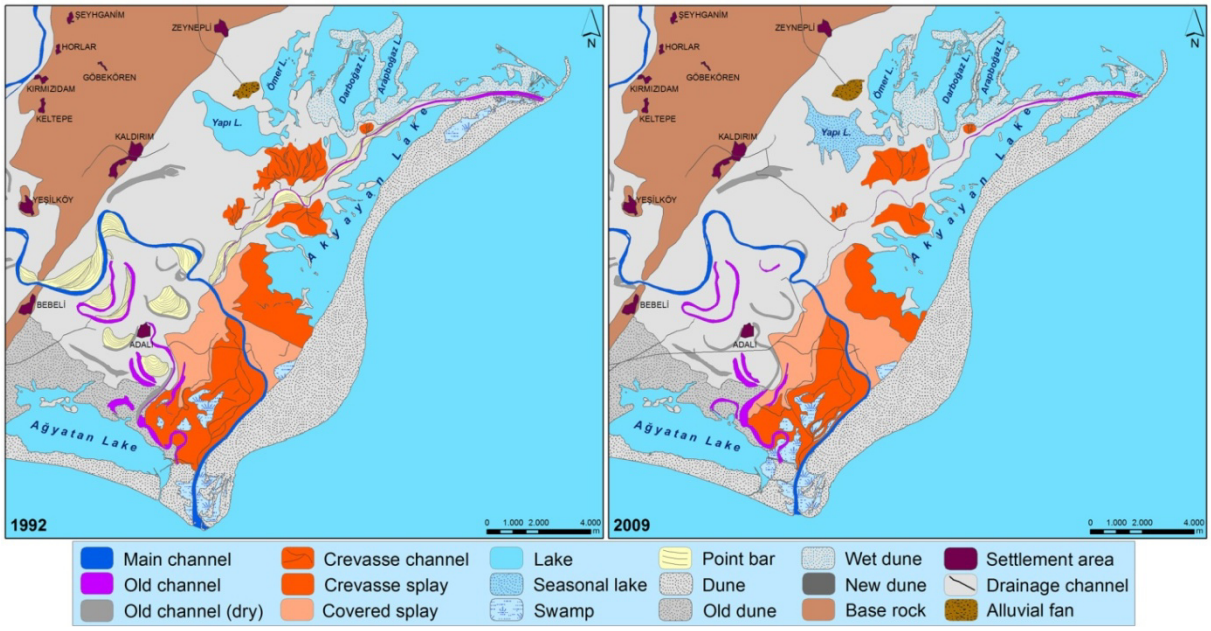

Fig. 5. (a) The view of Ceyhan Delta in 1992. (b) The view of Ceyhan Delta in 2009

4. Discussion

Millard (2013) has sorted the modern, recent and ancient splays according to size in the literature. Splay lengths of first three crevasse splays are 8600 m (Umbum Creek, Australia (Lang *et al*. 2004)), 7300 m and 4500 m (Colorado River, Texas (Aslan and Blum, 1999)). The length of the crevasse splay occured in Ceyhan Delta (Akyayan Lake Splay) is 4400 meters and the world's 4th largest crevasse splay. The barrier island that located in the south and the height is more than 10 meters in some parts, has prevented extension of this splay. Main crevasse channel (current Ceyhan river bed) is 9.1 km in length, hit this barrier and turned to the southwest.

Crevasse splays that arrive a lake are look like a lacustrine delta (Bridge, 2003). There are some examples about splays that occur on a lake (e.g. Smith and Perez Arlucea, 1994) or on a shallow marine environment (e.g. Coleman, 1976). There is not much example about modern crevasse splay that occur on a coastal lagoon in literature.

Smith *et al*. (1989) recognized three crevasse splay forms and named as stage I, stage II and stage III splays. Akyayan Lake Splay is a stage III splay. It has large size (25.8 km^2), low channel density and low channel width/depth ratio (main channel : 110 m / 3 m). Crevasse channels are stable. Besides, the main channel of splay became the main river bed of Ceyhan.

Lagoons where natural balance is protected are converted into lands in time depending on the sedimentation in the delta. This transformation can be very fast because of crevasse splays due to floods. The crevasse splay on the lagoon of Ceyhan Delta is a very good example of it. Ceyhan River started discharging its water through these channels on the splay and it took more than 30 years that multiple channels convert into single channel. Avulsion also changed the development direction of the delta and made it extend to the south.

On the other hand Ceyhan Delta is a very fertile agricultural land. Since soil formation on the crevasse splay is very recent, very limited portion of it was used for agricultural purposes until 1970s. These agricultural lands are located on the northeastern part where crevasse splay is like a thin cover on and formerly was land. The agricultural fields started enlarging on the crevasse splay in 1970s and after 1990s it was observed that large amount of agricultural fields were opened on the sedimentation in the delta. It is possible that chemical fertilisers are being used dense here where soil formation is not sufficient yet to get more crops. Such a case would decrease the water quality of the lagoons in the delta.

5. Conclusions

As a result of flood occurred on the current delta of Ceyhan River in 1935, a crevasse splay of 25.8 km^2 (7.5 km wide, 4.4 km long) occurred and Ceyhan River formed a new channel of 9.1 km on this new splay releasing its water at the southern edge of the delta. This crevasse splay converted 17.7 km^2 (%57.3 of the whole lake) of Lake Akyayan of 30.9 km^2 into land.

Today the east of the delta is in serious threat of coast declining due to avulsion. The main body of the delta is wave dominant whereas river dominant delta lobes that form lagoons in the northeast are observed. These are the best protected river dominated delta lobes in Turkey and are under threat due shoreline retreat in the eastern edge of the delta.

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