The Lower Valley and the Delta of the Rhône River: Water Landscapes of Nature and History

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Abstract

Linking the Mediterranean to northern Europe, the lower Rhône valley is the major axis of communication in the south of France since the antiquity. The valley ends by a large deltaic plain rich in history and landscapes of international renown. It annually attracts thousands of tourists and nature lovers and artists through several festivals and exhibitions. Original water landscapes were built in the valley and at the contact between the river and the sea (delta). Their development over the centuries is the product of a complex evolution between the natural environment and human history. Numerous archaeological excavations reflect man–environment interactions, emphasising the strong constraint of fluviatile–deltaic environments, and how human societies, since the Greeks and the Romans, found some parades to mitigate the fluvial risk. The geomorphology of the landscapes is most of the time discrete, and we must learn to decipher the old and recent landforms derived from fluvial, lagoonal or marine environments. The landforms are now subject to different aggressions (erosion, pollution) and metamorphoses related to human activities combining with the natural dynamics: the protection of the "nature" has become a real challenge.

Keywords

Water landscape • Palaeoenvironment and geoarchaeology • Biodiversity • Fluvial and marine hazards • Cultural heritage • Lower Rhône valley

20.1 Introduction

The Rhône delta, the so-called Camargue, is one of the major Mediterranean deltaic plains. Known as one of the most extensive natural areas (1,700 km^2) in Western Europe, the Rhône delta is famous for its vast sandy beaches and amphibious landscapes, which constitute an ornithological reserve of global importance, with white horses and black bulls living in freedom. These large "natural" spaces and their mythical inhabitants, the "gardians", were celebrated by both movies and literature, while the Gypsies gather every year at Les Saintes-Maries-de-la-Mer for their "Great Pilgrimage".

The location at the interface between a large anthropised catchment and a "closed" sea sensitive to pollution created original landform/landscape units downstream from the city of Avignon. It is an environment of great touristic, ecological, historical and societal importance, but fragile and under threat in the near future.

This text invites the reader to discover the main features of the (palaeo)environment of both the lower valley and the delta of the Rhône River, through urban and rural water landscapes representative of the area.

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20.2 Geographical and Geological Setting

The alluvial plain of the lower Rhône valley (Fig. 20.1) is situated downstream of a large catchment (97,800 km^2). At Avignon, towering the entire valley from the left side, Mt. Ventoux (1,800 m) is the last signal of the Alpine mountains range. Between Avignon and Arles, the river flows across alluvial basins alternating with resistant geological structures (E–W limestone folds). The historical sites such as the mediaeval castles in Avignon, Beaucaire and Tarascon or the Roman town in Arles were built on these "hard points".

From the alluvial plain to the delta, longitudinal channel profile and water surface slope decrease drastically (from 0.07 to 0.003 m/km), enhancing a drop in stream power and reinforcing the alluviation. The mean 1920–2007 annual discharge at the Beaucaire station is 1,720 m^3/s, influenced by the Mediterranean inputs from the downstream tributaries (Ardèche, Durance, Gard). The mean annual value of total wash load, which is estimated *ca.* 6.7×10^6 t at Arles (Antonelli et al. 2008), has been reduced by more than 75 % over the last 150 years in relation with deep climatic and socio-economic transformations in the fluvial catchment (reduction of the torrential erosion and the frequency in major floods at the end of the LIA, rural depopulation, gradual withdrawal of agriculture, reafforestation and building of Alpine reservoir dams).

At the apex of the "Camargue" delta, the Rhône River splits into two branches, the Grand Rhône (50 km) and the Petit Rhône (60 km), which export respectively 90 and 10 % of the discharge. The Grand Rhône, with a sub-straight channel, supplies an active prodelta in the Mediterranean. Its sediment plume plays an essential role in nutrient and contaminant inputs in the marine environment up to the Pyrenees. But the deltaic coastline is generally retrograding, and its lobed shape is due to the predominant action of marine erosion.

Fig. 20.1 The Rhône River in the lower valley and the delta. *1* Selected sites (sites 1–7 form the structure of Part 4, with 1 = Avignon, 2 = Arles, 3 = Petit Rhône, 4 = La Capelière, 5 = Aigues-Mortes, 6 = Les Saintes-Maries-de-la-Mer, 7 = Beauduc), *2* Resistant geological substrate, *3* Pleistocene terraces and fans, *4* Recent alluvium of the Rhône River and its tributaries, *5* Main cities, *6* Ddams managed by the National Company of the Rhône River (CNR), *7* Nuclear power plant of Marcoule (Credit: G. Arnaud-Fassetta and M. Provansal)

20.3 Evolution and Landforms

Between the slopes formed by the outcrop of the geological substrate or alluvial terraces, the alluvial and delta plains of the Rhône River include several landscape units. They are inherited from the recent geomorphological history and hydraulic structures that have modified the dynamics of fluvial forms and determine the spatial extent of current risk.

20.3.1 The Alluvial Plain, Between Avignon and the Deltaic Diffluence

Downstream of Avignon, the structural constraint reduced the extension of the alluvial plain. Between Beaucaire and Arles, the river pattern was controlled by a late-glacial palaeochannel incised into the Pleistocene deposits and joining a palaeo-coastal fringe located at − 120 m under the present sea level. During the Holocene, the Rhône River gradually infilled this palaeo-valley by adjusting its longitudinal profile to both the sea-level rise and mouth progradation advance. In alluvial basins, archaeological data showed several stages of braiding expansion, associated with rising groundwater, during periods of flood events and high detrital supplies (e.g. during the Little Ice Age, LIA; Bruneton et al. 2001). Alternatively, meandering periods correspond to a good natural drainage. Urban sites are located on highest points, usually geological bedrock outcrops (see sites 4.1. Avignon and 4.2. Arles).

Fig. 20.2 Some palaeochannels of the lower Rhône River. (**a**) *Lône des Pêcheurs*. At the kilometric point (Kp) 306.5, this channel was active until the early twentieth century. Its cross-section area was then reduced by aggradation of a large sandy bar on the riverbank. (**b**) *Lône Pillet* (Kp 272–276). This old channel was closed in 1870 by a longitudinal dyke then cross thresholds. Today, the palaeochannel is often flooded downstream but only inundated by moderate flood events upstream (Photographs by M. Provansal)

The Rhône channel is actually located at the top of a large alluvial ridge, which dominates the Holocene floodplain of several metres: breaches opened in its riverbanks during flood events that flooded very large areas. Since the end of the nineteenth century, changes in natural or socio-economic conditions (end of LIA, slowing down in mountain agriculture), then hydraulic structures (continuous unsubmersible dykes, groynes, compartments and barred arms (Fig. 20.2)

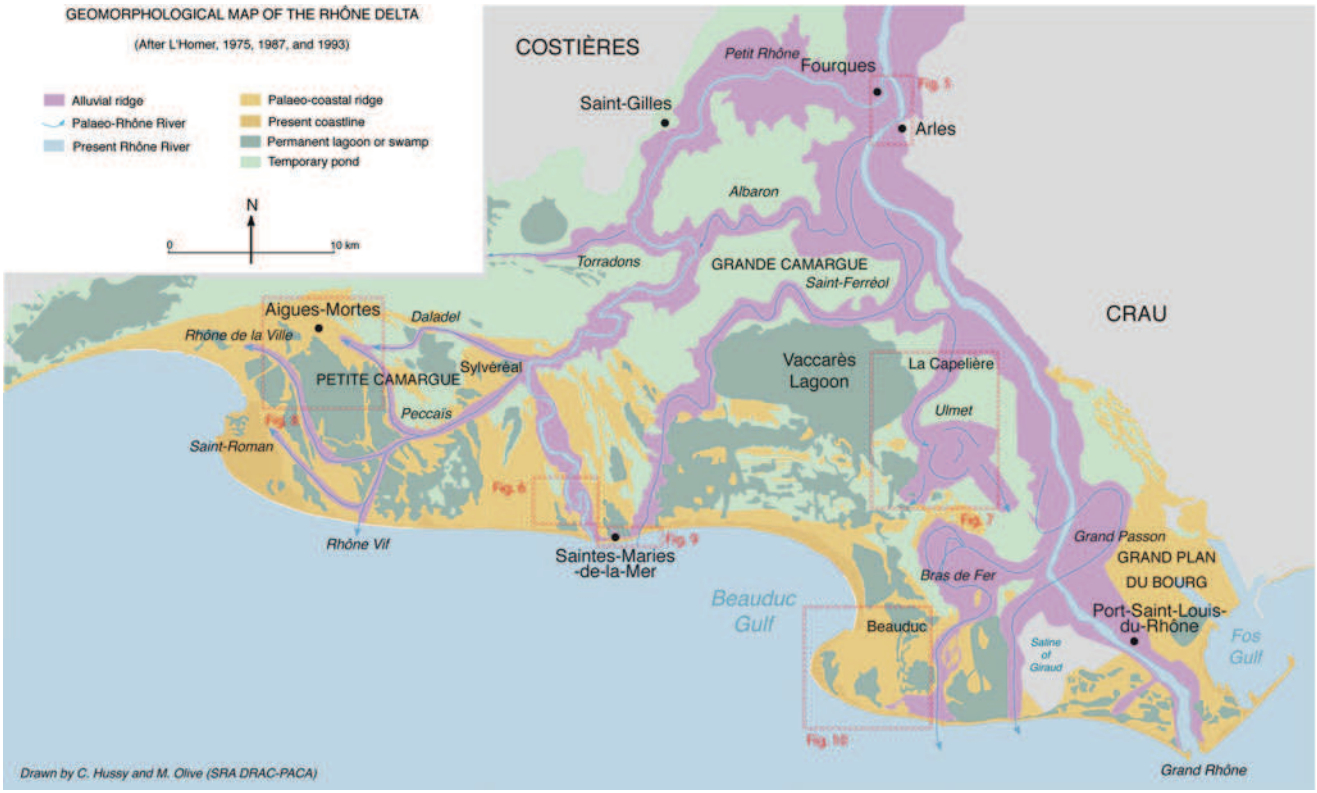

Fig. 20.3 Geomorphological map showing relationship between inherited and active landforms of the Rhône delta

and subsequently hydroelectric dams) induced channel adjustments resulting in a fluvial "metamorphosis" with a conversion of braided river pattern to a single, sinuous one (Arnaud-Fassetta 2003; Antonelli et al. 2004; Bravard 2010). Responses include simplification of channel morphology, erosion of the channel bed and infill of the alluvial margin, where the riparian forest is of great ecological richness (Provansal et al. 2010). The regulated channel is open for river navigation through a system of locks.

The lower Rhône River is located 70 km downstream of the Marcoule industrial radioactive releases: several studies give evidence for long-term retention of particle-reactive long-lived radionuclides in the fluvial margins and the "Camargue" delta (Provansal et al. 2012).

20.3.2 The Delta

The present plain corresponds to the top of a Holocene deltaic accumulation forming a sedimentary prism of more than 70-m thick to the south. Fluvial (alluvial ridges), brackish (salty lagoons) and coastal (sandbars) deposits unconformably overlie the Pleistocene alluvial gravel. River supplies lead to the advance of land surface since about 7,500 years ago, from a maximum shoreline situated to the north of the Vaccarès Lagoon (Fig. 20.3).

The Rhône River was divided, according to periods, in several branches, which patterns and mouths moved over time. Successive fluviatile channels, abandoned by avulsion, are still visible in the landscape: the oldest ones (6,500–2,000 BP) are located to the west, whereas the youngest ones are observed in the centre and east of the delta, including the two last branches: the Bras de Fer (1586–1712) and the Grand Rhône (since 1712).

The alluvial ridges of the former Rhône River (see site 4.4. La Capelière) and the coastal spits abandoned by shoreline advance form an irregular "grid" of sedimentary bodies higher (>2–3 m), sandy and better drained (the "*montilles*"), covered by crops and farms (the "*mas*"; Fig. 20.3). They delimit moist silty "lockers" which most of the time swampy. Fresh water dominates in the north, associated with *Phragmites australis*. Salt water characterises the southern part of the delta, associated with halophytic vegetation (the "*sansouire*"), where birds like to stay, especially flamingos, the emblem of the Camargue. The Vaccarès Lagoon (6,500 ha) is the largest and, like the other ones, protected by international labels (RAMSAR, UNESCO). Pesticides from agriculture (rice), however, disrupt the water quality. The rapid shoreline advance at times isolated marine lagoons, like that of Aigues-Mortes (see site 4.5).

The Grand Rhône River is slightly sinuous, while the Petit Rhône River develops several meanders, determined by Holocene geomorphic inheritance (see site 4.3. The Petit

Rhône River). Both branches were closely embanked in the late nineteenth century. In the Petit Rhône River, breaches in the riverbanks and dykes induce frequent inundation in the central or western part of the delta. The secular rise in sea level and storm surges, more frequent and higher than the surroundings during the twentieth century, considerably reduced the ability of the Rhône River to evacuate floodwaters to the sea, increasing the risk of flooding near river-mouths. The current coastline is formed by 70 km of sandy beaches backed by low dunes (<3 m) and unevenly degraded. Sectors of rapid erosion (see site 4.6. Les Saintes-Maries-de-la-Mer) alternate with well-developed sand spits (see site 4.7. Beauduc), but the overall sediment balance is negative on the coastline. Since many years, the sandy input from the two deltaic branches is insufficient to compensate erosion of the deltaic fringe.

20.4 Sites of Cultural Values and Touristic Promotion

20.4.1 The Site of Avignon

In Avignon, the Rhône River flows through a narrow rocky defile. Until the late nineteenth century, the river corresponded to the border between France (right bank) and the Holy Roman Empire and then the Papal lands (left bank). Two magnificent monuments face each other, the Chartreuse and Philippe Auguste Tower on the French side and the Palace of the Popes on the opposite side.

The Rhône River is now dammed by a hydroelectric dam. The slowdown of floodwaters upstream of the rocky defile and downstream of the city by the Durance confluence contributed over the centuries to the formation of many fluvial islands, mobile first and then stabilised. These islands were used as a substrate to build during the twelfth century, the famous Saint-Bénézet Bridge or *Pont d'Avignon*, sung by all the children of France (Fig. 20.4a).

From the fourteenth century, the terrible floods of the LIA, compounded by the effect of wars, eventually destroyed the bridge, despite several attempts to repair. Only a few arches have survived until today, siting on the limestone substrate on the left bank (Fig. 20.4b). Recent research has helped to locate the missing piles, to describe the "braided" pattern of the historical river, in which the main channel moved several times. At the entrance of the bridge, a beautiful museum gives the history and simulates the 3-D image of the original bridge.

20.4.2 Arles

The city of Arles is crossed by the Grand Rhône River, which meanders between a limestone outcrop and the beginning of deltaic land (Fig. 20.5). The river is a key element of the history and the development of the city since the Iron Age. Remarkable monuments were built during Roman times, such as the Antic theatre, the arena and the Alyscamps cemetery or the Roman circus. Because of its important heritage, Arles is classified by UNESCO since 1981. The *Musée départemental de l'Arles antique* was built in 1995 on the margin of the alluvial ridge where the Roman circus sited. Archaeological collections are particularly rich, and it will be possible to admire the oldest known bust of Caesar, who has been recently (2008) found at the bottom of the Grand Rhône River.

Considered as an important fluvial harbour since antiquity, the site of Arles has persisted despite the hydrological risk (Arnaud-Fassetta et al. 2005). The left bank in the upstream part of the city was affected by breaches and crevasse splays during protohistoric and Roman times; in the crossing of the city, it was also submerged several times (district of Sainte-Luce). The right bank at Trinquetaille recorded several flood events associated to crevasse splays and avulsions during Roman times, leading to the building of dykes and drainage structures. The plain extending south of the city (district of archaeological museum) was regularly flooded in the antiquity. Finally, the current urban sprawl spread in the floodplain, taking advantage of the low frequency of floods in the years 1960–1990.

20.4.3 The Petit Rhône Branch

The Petit Rhône is one of the two present fluvial branches of the Rhône delta, which marks the western edge of the Camargue. From its diffluence with the Grand Rhône in Fourques (north of Arles), the Petit Rhône is embanked all the way to the sea and joins the Mediterranean near Les Saintes-Maries-de-la-Mer after a sinuous/meandering course of 60 km through the deltaic plain. It is bordered by a riparian forest in its upstream section and by tamaris and "*sansouïre*" downstream where the channel is under influence of the salt wedge. It is possible (and recommended) to cross the river downstream by taking the scenic *Bac du Sauvage*.

The Petit Rhône branch is prone to the occurrence of crevasse splays during flood events (e.g. 1993–1994 and 2003; Arnaud-Fassetta 2013). Both human and material consequences of the December 2003 flood event were severe. However, this branch of the Rhône delta remains the most beautiful and most picturesque to make walking along its riverbanks, along which are installed fishermen's huts and large nets (the "*carrelets*"). Visiting the Petit Rhône by kayak or riverboats with a pair of paddle wheels allows one to explore its numerous meanders where there is an extraordinary freshwater avifauna (Fig. 20.6). The Petit Rhône is also a very popular river for sport fishing for giant catfish, a species introduced into the canal joining the rivers Rhône and Rhine in 1868.

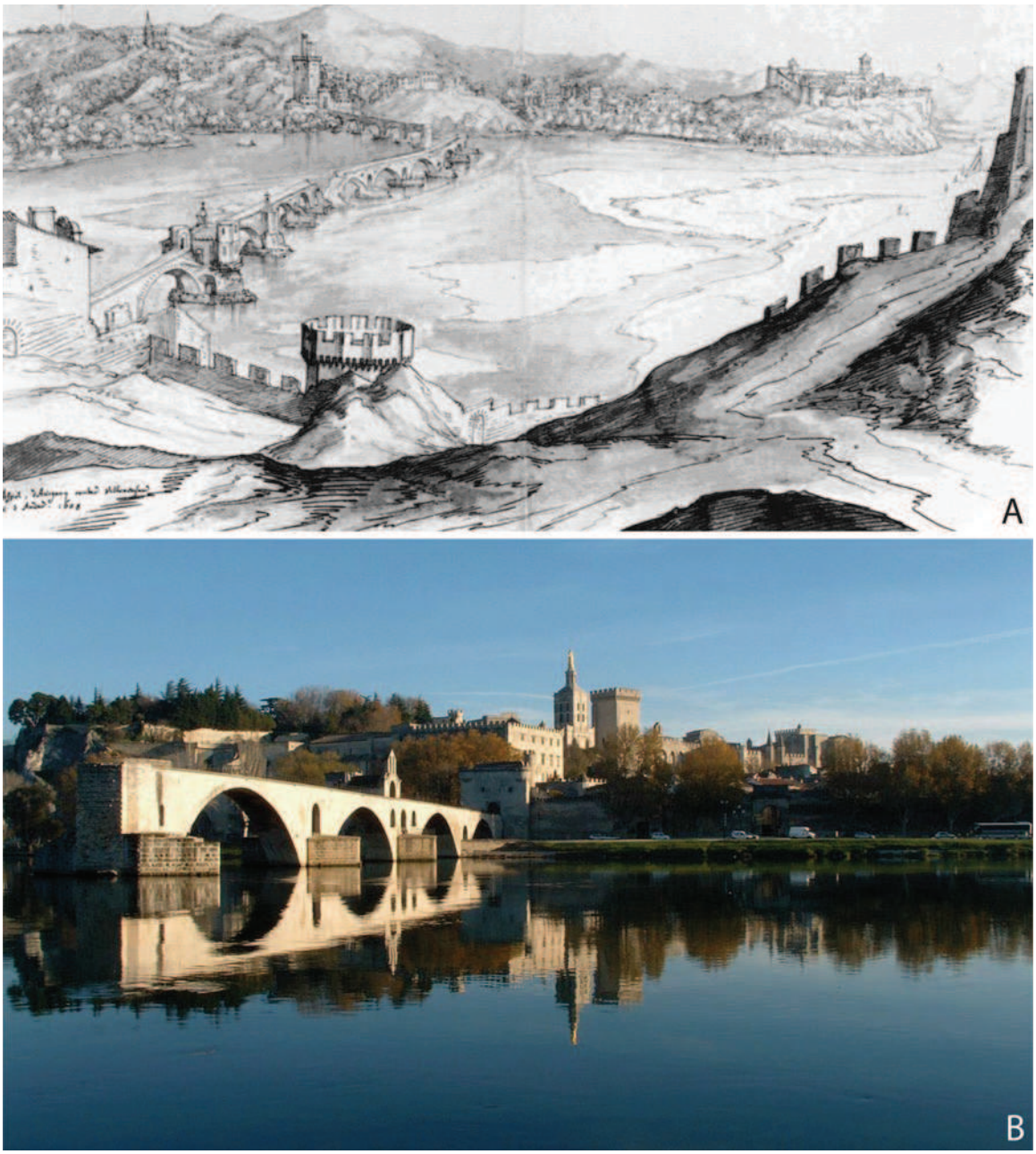

Fig. 20.4 Hydraulic structure facing vagaries of time. (**a**) The broken bridge of Avignon (engraving, 1608). (**b**) The Avignon Bridge and the Palace of Popes (From Wikipedia 2004). It did not resist to flood events during the LIA

20.4.4 The Archaeological Sites on the Former Branches of the Rhône River, La Capelière

In the Camargue, the first known archaeological sites date back to the sixth century BC. The deltaic lands were an obvious strategic position for the city of Marseilles, founded by the Greeks who wanted to control the Rhône River and the hinterland. From the first century BC, habitats (grouped settlements; *villae*) multiplied, mainly in the north of the Camargue. The southern Camargue revealed the existence of a mosaic of large *villae* and agricultural settlements during the antic period. The archaeological sites essentially established along the old branches of the Rhône River (Arnaud-Fassetta and Landuré 2003). Societal vulnerability faced to flood hazard was lessened, by settling on the highest points of the alluvial ridges.

Some sites were temporarily abandoned or unoccupied during period of hydrographical disorder. On the site of La Capelière, a small rural settlement was built on the bumpy

Fig. 20.5 The site of Arles (Photograph by P.-L. Ferrandez). Note the Grand Rhône River in the background and development of the antic city of Arles on the *left* bank in the foreground

Fig. 20.6 The last tight meander of the Petit Rhône River (Photograph by Tiki III, *mini-croisière camarguaise*) before the river mouth

Fig. 20.7 The archaeological site of La Capelière (fifth century BC to fifth century AD) on the Ulmet alluvial palaeo-ridge bordering the eastern bank of the Vaccarès Lagoon (Photographs by C. Hussy) (**a**), G. Arnaud-Fassetta (**b**), and C. Landuré (**c**)

sandy-silt flood deposits right from the beginning of the occupation (fifth century BC). The site suffered from floods and crevasse splays. That is why human occupation levels of the first century BC were completely recovered by sandy-silt deposits of a crevasse splay, in which structures and amphoras were fossilised (Fig. 20.7). After these catastrophic

Fig. 20.8 The site of Aigues-Mortes (photograph by F. Hédelin). Constance Tower is in the foreground, salt pans in the background

floods, which probably appeared in the second half of the first century BC, the settlement was abandoned and reoccupied some decades later (~AD 30). Visiting the site, it is now possible, by joining the Camargue National Reserve, to observe traces of old channels of the Rhône River (the "*lônes*") and archaeological site of La Capelière now scattered in the salt marshes where salicornia dominates.

20.4.5 Aigues-Mortes

The landscapes around Aigues-Mortes are composed of wet zones (flood plains, ponds and lagoons) associated to sand dunes, which form the Petite Camargue (Fig. 20.8). Delta construction was relatively late in this area since no deltaic lobe was developed before Roman times. The main part of the deltaic infilling occurred during the historical period, thanks to the sedimentary supplies from several palaeochannels located to the south of Aigues-Mortes (Fig. 20.3).

It is in Aigues-Mortes that Saint Louis, King of France, sailed in 1248 for the Seventh Crusade. The harbour of Aigues-Mortes was more inland on the edge of the Marette Lagoon. At the beginning of the fourteenth century, Philippe le Bel used the fortified site of Aigues-Mortes to incarcerate the Templiers in the Tower of Constance (Fig. 20.8). This tower is also notorious because it was particularly a Protestant women's place of imprisonment after the revocation of the Edict of Nantes. The Desert Museum pays a warm tribute to these Cévenol prisoners who resisted to the repression of Louis XIV, while their husbands were dying on the galleys.

From the early fifteenth century, significant work was undertaken to facilitate access to the sea from Aigues-Mortes since the site is exposed to recurring silting. The year 1806 saw Aigues-Mortes become a fluvial harbour through the "*Canal du Rhône à Sète*".

20.4.6 Les Saintes-Maries-de-la-Mer

At the mouth of the Petit Rhône River, the site of Les Saintes-Maries-de-la-Mer has been inhabited since the Middle Ages, as evidenced by the fortified church built in the eleventh to twelfth centuries. Legend has it that the three *Saintes Maries* (Madeleine, Jacobé and Salomé), fleeing Egypt, landed here at the beginning of the Christian era. The Pilgrimage of the Gypsies from all over Europe commemorates this event

Fig. 20.9 (**a**) The beach of Les Saintes-Maries-de-la-Mer in 1888 (V. Van Gogh, Public domain). (**b**) Coastline between Les Saintes-Maries-de-la-Mer (background) and La Gacholle in the National Reserve of Camargue, south of the *Digue à la Mer* on March 16, 2010 (Photograph by M. Gauthier Clerc)

every spring. The poet Mistral made die also his heroine, Mireille, whose statue is established on the main place.

Les Saintes-Maries-de-la-Mer offers a beautiful synthesis of traditional symbols of the Camargue: salt marshes with typical houses of the "gardians", white horses and black bulls, arena devoted to the bull race (the "*Course à la cocarde*") and sandy beaches immortalised by Van Gogh (Fig. 20.9a). But the site, which was originally more than 1 km from the sea, is currently threatened by shoreline erosion (several metres per year; Fig. 20.9b). Indeed, the Petit Rhône River supplies no more enough sediment in order to resist to wave erosion, whose impact is exacerbated by the present sea-level rise (Sabatier et al. 2006). Many structures (dams, wave breakers, groynes) degrade the natural landscape and do not protect the coastal fringe in the medium term. The site is now part of an important challenge for choosing a sustainable coastal development.

Fig. 20.10 The Beauduc spit. Note the breach trough the coastal ridge, the wash-over channel and the wash-over fan *left* (west) to the Beauduc lighthouse (Photograph by M. Gauthier Clerc)

20.4.7 The Site of Beauduc

The beach and dunes of Beauduc are located in the central part of the deltaic fringe. We can reach this site by a dirt road 12-km long through the marshes where flamingos have now a sustainable habitat. Located at the bottom of a large gulf occupied by shallow water, the beach is very wide, further expands each year and is surrounded by a vast field of wild, white sand dunes (Fig. 20.10). This "World's End" is the end of a spit, still well supplied by sand derived from the erosion of the old mouth of the Bras de Fer (Sabatier et al. 2006; Fig. 20.3).

This is a very original site, between nature and culture, frequented by clam fishermen, surfers, loners and the international gentry. It is famous for its hamlet of eclectic "sheds", built after the Second World War, from recycled materials, old fishermen's huts, caravans and buses. In order to preserve this unique environment, the management of this space was disputed between the locals and State agencies. But the hamlet will be saved in order to preserve its original cultural heritage.

20.5 Conclusion

The lower valley and the delta of the Rhône River are attractive areas for their natural richness, the beauty of their landscapes and the importance of historical and cultural heritage, raising contemporary issues on the relationship between societies and their environment.

On the side of natural resources and landscapes, we highlight the large wetlands, whose ornithological richness is known worldwide; the vast sandy beaches of the Camargue; and the biodiversified riparian forest that runs along the river. Both historical and cultural heritage certainly deserve a visit, for the beauty of the monuments still in place in the old cities of Arles and Avignon, the deltaic sites and popular festivities.

Finally, this famous area is now the holder of an interesting debate concerning the limits of acceptable risk, whether induced by rigid hydraulic structures dating from the nineteenth to twentieth centuries or by the effects of climate change on sea-level rise.

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