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Modern Caspian Deltas as Analogues for the Productive Series, Azerbaijan

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Introduction

The Pliocene Productive Series and the coeval Red-Coloured Series, the main reservoir units of the prolific hydrocarbon province in the South Caspian Basin, represent the lowstand wedge of the most dramatic sea-level fall the Caspian Sea has ever experienced. They consist of an up to 8 km thick succession of fluviodeltaic sediments, deposited at extremely high sedimentation rates (2-4 mm/y) by the Paleo-Volga, Paleo-Kura and Paleo-Amu Darya Rivers in the narrow, rapidly subsiding South Caspian Basin between 5.4 and 3.3 Ma ago (Jones & Simmmons, 1996; Reynolds et al., 1998). Simultaneously, the Paleo-Volga carved a canyon 2000km long and up to 600 m deep far upstream into the Russian plain. The sedimentary succession in the proximal part of the Productive Series shows the transition from an alternation of channel and sheetflood sandstones and floodplain mudstones with great lateral continuity to finer-grained packages in which fluviodeltaic coarsening upwards sequences predominate and evidence of frequent emergence and desiccation is present (Hinds et al., in review; Kroonenberg et al., in review). A coarser-grained interval probably reflects initial uplift in the adjacent Greater Caucasus mountains (Morton et al., 2003).

In contrast to many other large-river deltaic sequences, the Productive Series does not easily fit into schemes of global sea-level change, because during its deposition the Caspian was a closed basin with a sea-level regime of its own. In historic time and in the Holocene Caspian sea level fluctuated much more rapidly and with much greater amplitudes than the oceans, and the stratigraphies of modern Caspian deltas therefore differ considerably from those of modern ocean-bound deltas. This is likely to have been the case as well in the Pliocene, and therefore we studied modern Caspian deltas of the same rivers that deposited the Productive Series as analogues to improve our understanding of reservoir architecture.

The Paleo-Volga and the modern Volga

The Productive Series in the South Caspian Basin and the modern Volga delta in the northern Caspian Sea are deltas deposited by the same river into the same closed sea. Both deltas are low-gradient, fines-dominated, river-dominated, multichannel ramp deltas without a shelf break, and show the impact of rapid changes in sea level and climate-driven discharge and sediment input.

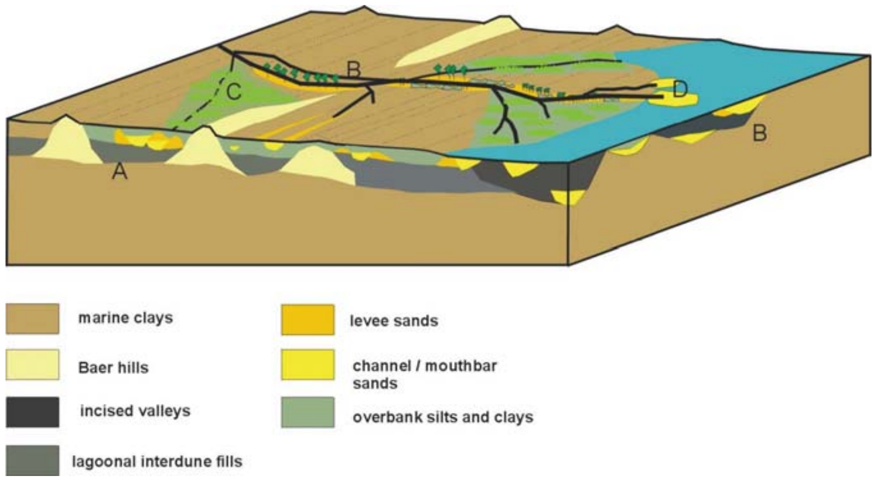

Fig. 1. Depositional model modern Volga delta

In contrast to the Productive Series, the modern Volga delta is deposited on a wide stable continental platform. It shows rapid lateral and vertical facies changes at the delta front, many small radial sand bodies with low connectivity, coarsening upwards mouthbar and levee sequences over clayey prodelta deposits, and fining upwards channel fills. Sea-level fall leads to rapid progradation of small sandy levees over the extremely gentle ramp surface, and only when sea-level falls beyond the shelf edge, at 15 m depth at 200 km offshore from the present delta front, incised valleys start to form. Sea-level rise leads to aggradation as long as vegetation growth can keep pace with sea-level rise. Overstepping and retrogradation only occur when sea level rise exceeds 3 metres or more. There is evidence of frequent emergence and submergence, leading to salinization and occasional evaporite deposition in isolated lakes. Average sedimentation rates are comparatively low (0.7-1 mm/y). Rapid sea-level change in the Pleistocene led to continuous depocenter switching over a surface area of several 100,000 km^2, and the modern delta lobe (<6000 BP) is less than 10 m thick (Overeem et al., 2003; Kroonenberg et al., 1997 and in review).

It is argued that the coarsening upwards sequences in the upper part of the Productive Series have been deposited in a similar way as in the modern delta, i.e. by progradation during sea level fall across a gently sloping ramp. Deposition of thin gypsum layers, desiccation cracks and reddish intervals in the Productive Series do not necessary point to increasing aridization, but are in harmony with rapid base level change near the front of a gently sloping ramp delta as in the modern Volga delta. The upsection increase in mud-dominated deposition in the Productive Series is thought to reflect a trend towards more humid climates in the Volga drainage basin, which is corroborated by the transgression of the uppermost part of the Productive Series into the Middle Caspian, by ostracod data and data from coeval Volga canyon infills further upstream (Kroonenberg et al, in review). The modern Volga delta seems less suitable an analogue for the lower parts of the Productive Series, which is hardly surprising in view of the differences in depositional time (<6ka vs. 2Ma) and sediment thicknesses (10m vs. 8km) between them.

Higher sedimentation rates in the Productive Series are to be expected in view of the greater drainage basin and canyon downcutting by the Paleo-Volga. Nevertheless, part of the differences in sedimentation rates is a 2-D optical illusion, as the Paleo-Volga shed its load in a narrow, rapidly subsiding basin, while the present Volga spreads its sediment in depocenters shifting across a wide, stable, shallow continental platform. When calculating sedimentation rates 3-D basin configuration should always be taken into account. (Kroonenberg et al., in review).

The Paleo-Kura and the modern Kura

The Paleo-Kura drained the larger parts of the emerging Greater and Lesser Caucasus, just like the modern Kura, and flowed across the desiccated Kura basin before merging with the Paleo-Volga delta in the South Caspian Basin. Also the Paleo-Kura part of the Productive Series started with deposition after a major regression. The apex of the Paleo-Kura fluviodeltaic plain in Productive Series time was situated near Kurdamir, much more seaward than at present. Pliocene and recent Kura sediments are much more immature mineralogically, which might affect their reservoir properties (Khain and Shardanov, 1953, Morton et al., 2003). The modern Kura delta was studied as a possible analogue of the Paleo-Kura offshore fields, notably the Inam field. During three field campaigns, 40 augerings up to 7m depth were made in the onshore delta, offshore 18 sparker profiles were shot and 14 piston cores down to 3m and 8 wells down to 20m were drilled. Laboratory analysis comprised grain size analysis by sieving and laser methods, light and heavy fraction petrography, chemical analysis of $CaCO_3$ and organic matter, biostratigraphical analysis using ostracod, foraminifera, mollusc and diatom countings, and radiometric dating using ^{210}Pb and ^{14}C analysis. The onshore data are complemented by 3-D stochastic and 2-D numerical modelling (Boels et al., 2003).

The data have given a concise insight in the development of the delta during the last ~1500 years. They show at least three and possible four phases of delta progradation during highstands of the Caspian Sea, interrupted by erosional phases during lowstands, recognisable in the sparker profiles as prominent reflectors. The first phase is represented by reddened fluvial(?) clays (RST1) possibly affected by soil formation during a lowstand at –80m absolute depth (SB1). These are overlain by several metres of laminated clays and silts, ^{14}C dated at >1400-900 BP on shelly intervals, and shown by microfauna to have deposited in a shallowing sea (RST2). This succession is truncated by the prominent SB2 reflector, corresponding to a lowstand at about –48m absolute depth and correlated with the 11th century AD Derbent Regression known from historical and archeological data. It is overlain by another metres-thick, undated succession of laminated deltaic clays and silts, passing locally to organic clays with fluvial diatom assemblages (RST3). This horizon is also truncated by an erosional event SB3 probably related to a lowstand in the 16th century AD. During the Little Ice Age highstand the Kura river was diverted southwards to the Qızılağaç Bay and the barrier coast at the apex of the modern delta was formed. The last phase RST4 is represented by the formation of

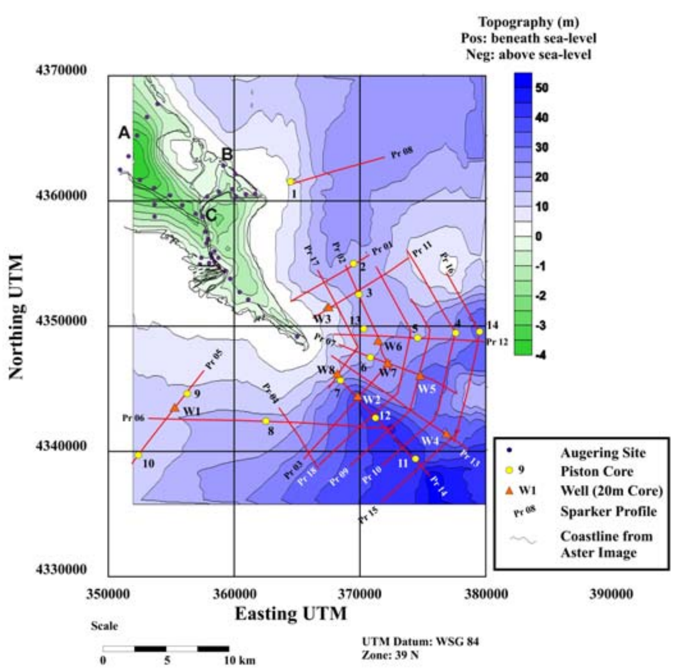

Fig 2. Kura delta sparker survey and drilling

the onshore Kura delta since the end of the 18th century and an offshore correlative veneer of clays and silts, dated using ^{210}Pb as having also been deposited during the last 200 years. The onshore delta consists of progradational sequences of channel-levee sands and floodplain silts and clays deposited on top of stage RST3 clays during gradual sea-level fall, overlain by clays reflecting the last phase of rapid sea-level rise since 1977. Along the northern shore of the delta sands are deposited in narrow coastal barriers and beaches. Overall sedimentation rates in the delta determined by various methods range between 1.5-3 cm/year.

Except for the thin and narrow sand bodies in the channels and barriers of the onshore plain, the whole Kura delta consists of clays and silts with virtually no reservoir capacity. In this respect the modern Kura delta differs from the sand-rich Pliocene Paleo-Kura Productive Series exposed e.g. at Babazanan and presumably also offshore. This is due to two factors. In the first place strong subsidence of the onshore Kura depression probably started only after deposition of the Productive Series and simultaneously with the main uplift phase of the Greater Caucasus. Therefore, most of the modern Kura sand is probably trapped further upstream, where subsidence of the Kura trough is greatest. In the second place, unlike the situation in Pliocene times, present-day sedimentation can no longer keep pace with rapid subsidence of the South Caspian Basin itself. As a result, the slope offshore the mouth of the modern Kura delta is much steeper, and therefore the modern Kura delta is no longer a ramp delta, but a single-channel cuspate-lobate delta with an offshore break like so many others, differing in depositional environment from the Paleo-Kura ramp delta.

Conclusions

Modern Caspian deltas have the drainage basin, sediment composition and unstable sea-level history in common with their Productive Series counterparts, and this leads to a better understanding of some sedimentary features in the latter, as for instance shown by the similarity of coarsening-upwards sequences in the upper part of the Productive Series to those in the modern Volga. However, basin geometry of both the modern Volga and the modern Kura deltas differs radically from that of their Pliocene equivalents, due to active tectonics and paleogeographic changes since the deposition of the Productive Series. This confirms that analogue studies are useful, but do not obviate the need to regard each delta in the geological record as a unique sedimentary body.

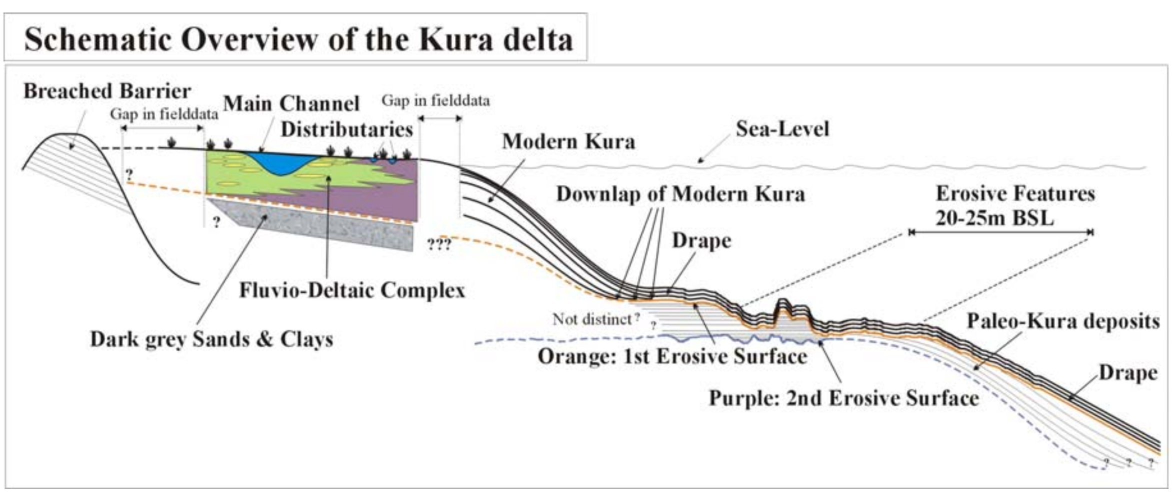

Fig. 3. Schematic onshore-offshore alongstream cross-section of modern Kura Delta (Boels et al., 2003)

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