North Dakota Geological Survey
Geologic Investigation No. 193
Plate II

Sequence Stratigraphy of the Inyan Kara Formation, Northwestern North Dakota
Extracting the Maximum from Minimal Core and Outcrop Data

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The Core

The Amerada Petroleum Corporation, Math Iverson #1 well was cored in the upper and lower portions of the Inyan Kara (Fig. 5). The core was accessed and described in detail at the NDGS Core Library. Lithology, sedimentary structures, and sequence stratigraphic surfaces were logged and then compared to well logs (gamma ray, resistivity, and neutron). The Inyan Kara in this well is characterized by two coarsening/fining upwards packages, as exemplified on the gamma-ray log and observed in core (Fig. 5). The deeper core (4,586-4,644 ft.) consists almost entirely of very fine- to medium-grained sandstone that unconformably overlies the Jurassic Swift Formation and represents the lower portion of the first coarsening/fining upwards package. The shallower core (4,937-4,980 ft.) shows an overall fining upwards sequence with a silty, bioturbated, very fine-grained sandstone sandwiched between finer-grained siltstone/claystone, of which the upper eight ft. is the conformably overlying Skull Creek Formation. The shallower core represents the upper portion of the second coarsening/fining upwards package.

Incised Valley Evolution

The Dakota Group of North Dakota has not been described in terms of sedimentary environments except in the most general sense, probably because the formation does not crop out in the state. However, studies by Willis (1997) of the Inyan Kara equivalent Fall River Formation in southwestern South Dakota suggest that the Inyan Kara of North Dakota may represent an incised valley complex that would have been present along the eastern margins of the Cretaceous Western Interior Seaway of South and North Dakota. The Math Iverson #1 core and log pattern are consistent with this interpretation and provide a type log/core for which a working hypothesis can be constructed and modeled (Fig.6). Because of the paralic nature of the Inyan Kara deposits, the unit presents an ideal succession of rock that can be interpreted using fundamental sequence stratigraphic principles related to relative sea-level rise/fall during the Early Cretaceous. In addition, the prodigious amounts of drilling in western North Dakota provides an unusually robust population of wells allowing for detailed stratigraphic correlation and evaluation. Utilizing sea-level curves and sequence stratigraphic principles, likely depositional environments and systems tracts can be anticipated and then compared to log stacking-patterns and core as shown on Figs. 6, 7, 8, and 9. Cores from the Math Iverson #1 show sedimentary structures and sequence stratigraphic surfaces consistent with deposition in an incised valley system. Overall, the Inyan Kara is characterized by two regressive/transgressive sequences that occurred after the initial sea-level rise in the Early Cretaceous.

Sequence Stratigraphy

Utilization of sequence stratigraphic principles is critical to understanding siliciclastic deposition and reservoir quality in paralic systems. Two full depositional sequences, from falling stage through high stand can be recognized on the Amerada Petroleum Corporation, Math Iverson #1 core/log (Figs. 8 and 9). Valley-fill deposits rest unconformably (SU) over previous high stand deposits (HST) in each sequence. The valley-fill deposits are both regressive (LST) and transgressive (TST) and separated by a maximum regressive surface (MRS) that can be seen on both log and in core. The transgressive valley-fill is capped by a transgressive lag deposit (WRS), which is in turn overlain by estuarine deposits (TST) that are capped by a maximum flooding surface (MFS). High stand deposits (HST) are at the top of each sequence and include the previously described Skull Creek deposits in the upper eight feet of the shallower core. This interpretation is consistent with sea-level curve and incised valley evolution models (Fig. 8B) and allows for a simple comparison of expected surfaces from the relative sea-level model to what is actually seen in core (Figs. 8A and 8C). In addition, major transgressive/regressive events recognized in paleogeographic models (Blakey, 2014) correspond to the various systems tracts identified in the study (Fig. 9).

Reservoir Characteristics

Permeability and porosity values for valley-fill sandstones are good to excellent as compared to other sandstone bodies (Fig. 9). Regressive valley-fill sandstones provide the best reservoir quality with Darcy level permeabilities and over 20% porosities, making them ideal for produced water disposal in North Dakota, as well as excellent oil and gas reservoirs in Canada and Wyoming.

The Model

Figure 10 presents an Inyan Kara sequence stratigraphic model that extends across the entire Williston Basin from southeast North Dakota into the Edmonton Valley of Alberta. The model uses sequence stratigraphic surfaces identified in the Amerada Petroleum Corporation, Math Iverson #1 (NDIC #165 on Fig. 10) core/log and extends them landward (SE) and basinward (NW) using sequence stratigraphic principles (shoreline and relative sea-level rise/fall diagrams) to depict evolution of the shoreline during Inyan Kara time. Select logs were reviewed in generation of the model and a few are included from SE North Dakota, where the Inyan Kara is completely fluvial in nature. Logs from Canada were also reviewed for development of the model. Two valley-fill packages can be observed on the model; the first extending nearly to Edmonton, Alberta, and the second only extending just across the U.S./Canada border. The extent of these valley fills mark the approximate extent of the maximum regressions during Inyan Kara time (Figs. 9A, 9D, and 10). Two falling stage events (I and II) are also depicted, showing both pre- and post-incision surfaces.

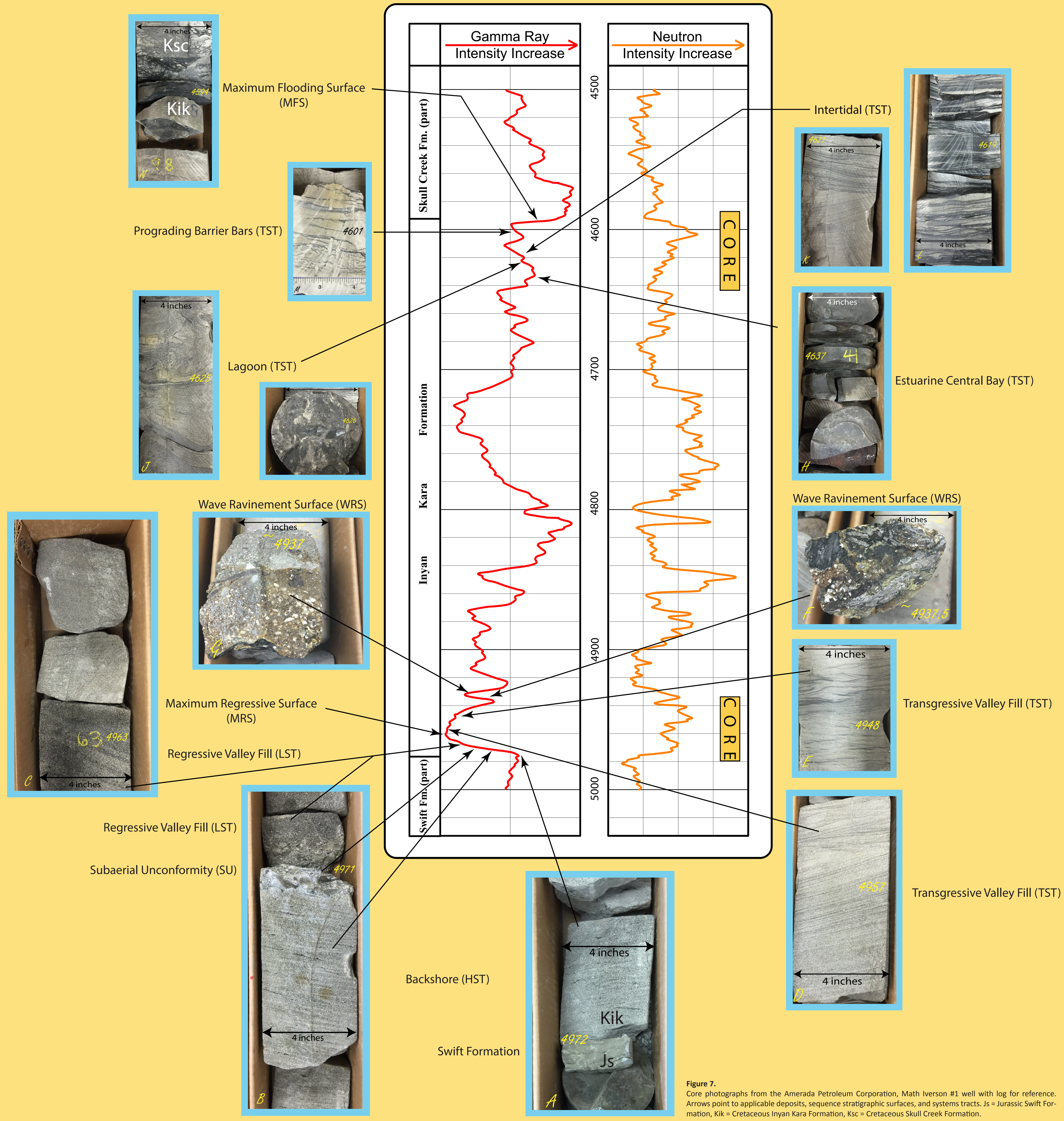

Figure 7.
Core photographs from the Amerada Petroleum Corporation, Math Iverson #1 well with log for reference. Arrows point to applicable deposits, sequence stratigraphic surfaces, and systems tracts. Js = Jurassic Swift Formation, Kik = Cretaceous Inyan Kara Formation, Ksc = Cretaceous Skull Creek Formation.

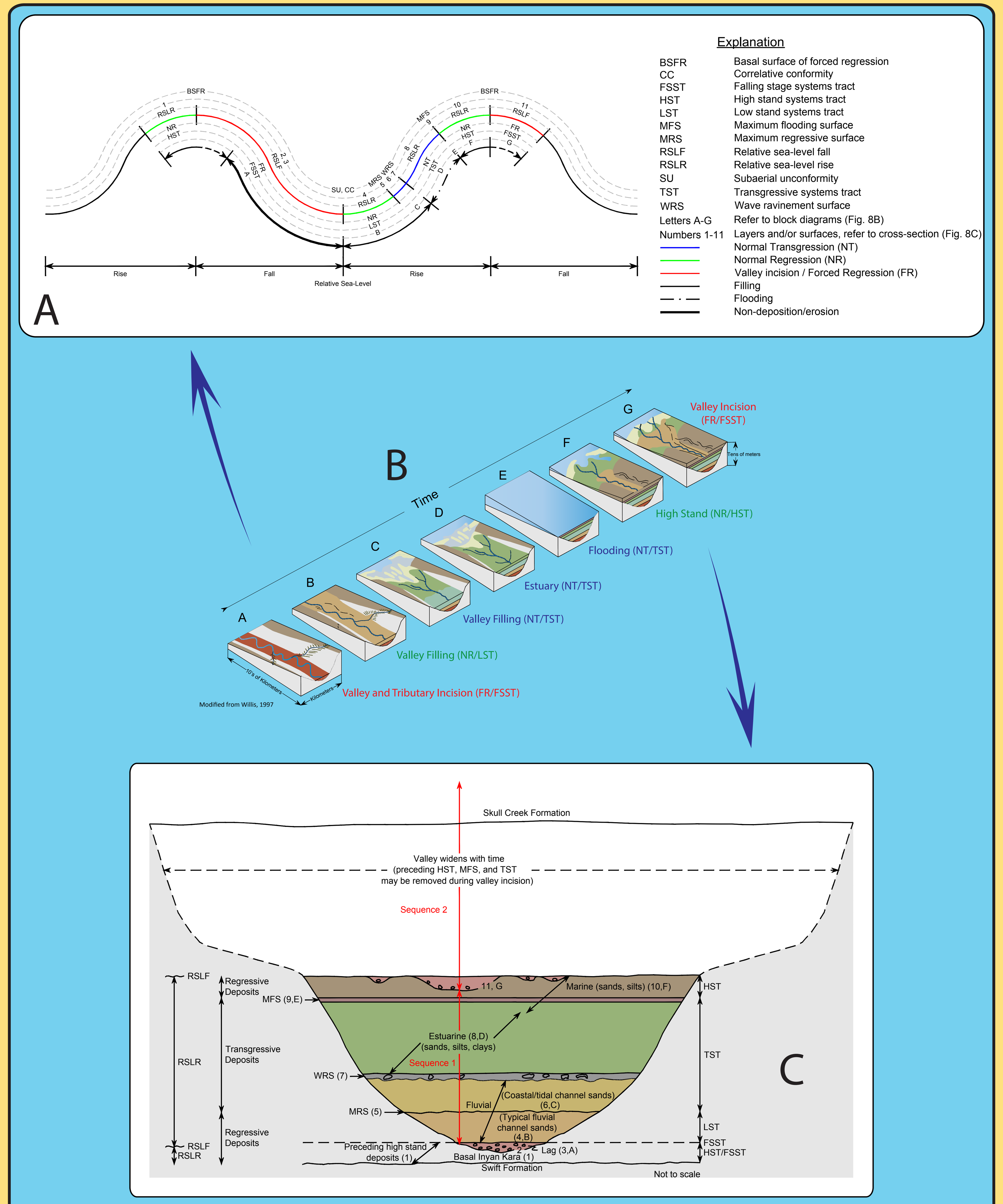

Figure 8.
Model for evolution of an incised valley at a transgressive river mouth (Fig. 8B) as compared to a detailed relative sea-level curve (Fig. 8A) and a graphic representation of the lower sequence of the Amerada Petroleum Corporation, Math Iverson #1 well (Fig. 8C). Letters A-G, refer to block diagrams (Fig. 8B); Numbers 1-11 are layers and/or surfaces, refer to relative sea-level curve (Fig. 8A).

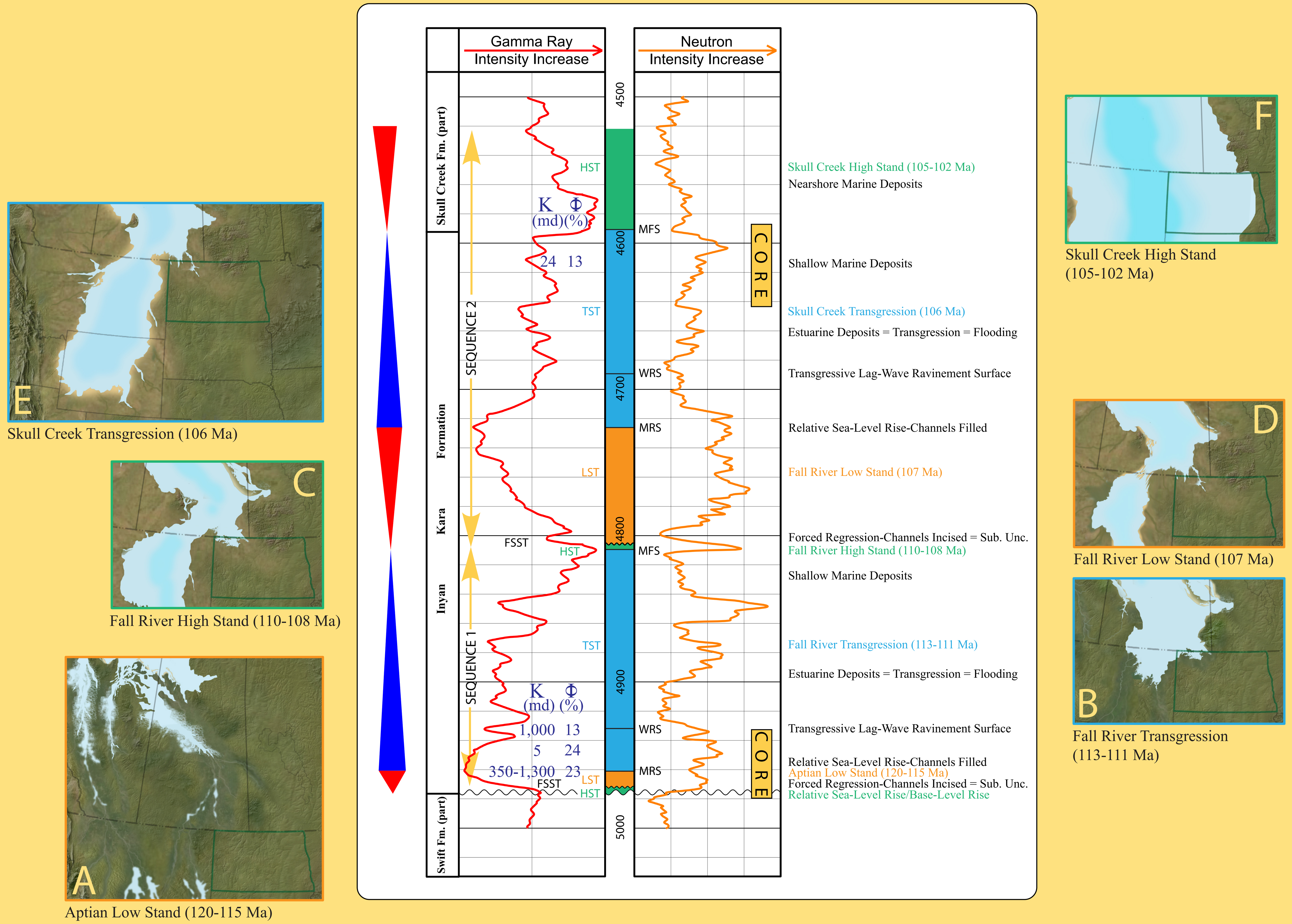

Figure 9.
Summary plate of the Amerada Petroleum Corporation, Math Iverson #1 well log showing sequence stratigraphic surfaces, system tracts, and sequence boundaries along with corresponding depositional events. Red (regression) and blue (transgression) triangle symbols are presented at the left for comparison. Paleogeographic images (Blakey, 2014) from major transgressive/regressive events (Figs. 9A-F).