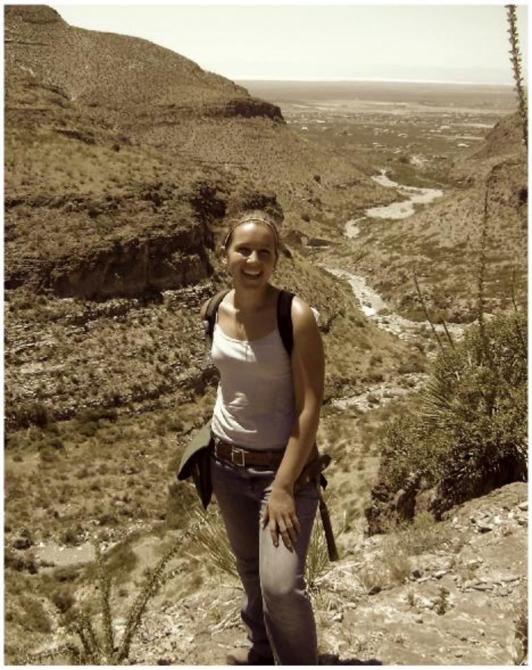

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Landform distribution on modern coastal distributive fluvial systems (DFSs) and predictions regarding ancient coastal plain progradational successions

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Problem/Purpose of Study

Current fluvial to marginal marine facies models are primarily based on modern degradational to aggradational, tributive fluvial systems held in incised valleys (i.e., Mississippi River; Blum, 1993; Blum and Valastro, 1994; Blum and Tornqvist, 2000). However only a small area relative to the overall coastal plain and are incised into pre-existing coastal plain deposits during certain climatic regimes or sea level positions (Zaitlin et al., 1994; McCarthy et al., 1999). An alternative view consists of aggrading distributive fluvial systems (DFSs) forming a broad coastal plain, that eventually progrades over the marine system (Fig. 1a). **I hypothesize that coastal plain fluvial successions are dominated by DFSs, with incised valley fill deposits comprising only a small portion of fluvial fill.**

Incised valley systems (IVS) are linear topographic lows created by fluvial incision into coastal plain to marine strata. The valley fill shows a basinward shift in depositional faces and is floored by a basal erosion surface that is traceable to an exposure surface. IVS deposits show an overall fining-upward motif characterized by amalgamated channel belts above the incision surface that grade upward into a succession dominated by floodplain fines. Hence, vertical trends consist of a decrease in both sand:mud ratio and sand body grain size, with an increase in proportion of floodplain fines (Fig. 1b-c).

If the basin edge in a coastal regime is located up-dip from the shoreline, then one would expect stream systems entering the basin to exhibit an overall distributive morphology. This pattern is a consequence of confined valley streams entering a broad basin and losing transport capacity, which leads to channel aggradation and radial migration over time. This process is seen at all scales (from flume studies (Strong and Paola, 2006) to fluvial mega-fans (Geddes, 1960)) and in all depositional systems (from submarine fans to alluvial fans) (Walker, 1992).

Many ancient regressive, marginal marine to fluvial clastic wedges prograde toward the basin center (e.g., Cretaceous of western US), thus I envision these to be dominated by DFSs draining the hinterland. A purely progradational DFS succession exhibits a vertical increase in channel belt size, sand body amalgamation and sand body grain size, with a corresponding decrease in overbank fines, coals and tidally-influenced channel strata (Fig. 1b-c). Since the resulting suite of deposits in each setting is distinct, the DFS hypothesis can be tested against the dominant paradigm of incised valley systems (IVS) by documenting detailed alluvial architecture both laterally and vertically across large portions of outcrop and in the subsurface. Most authors have proposed eustatic vs tectonic controls on shallow marine and fluvial deposition in foreland settings (e.g., Shanley and McCabe, 1994; Van Wagoner, 1995; Little, 1997), but only recent studies (McNamara et al., 2011; Rittersbacher et al., 2011) have applied a DFS alternative to explain vertical and spatial trends in coastal progradational fluvial deposits.

Significance

Fluvial to marginal marine deposits are important sedimentologic regions in the natural resource industry sectors, yet facies models are based on dominantly degradational, tributive systems or valley fill models (e.g., Mississippi River, Texas Coastal Plain) at the outcrop- and borehole-scale. Many studies of coastal progradational successions focus on vertical trends in fluvial architecture (Shanley and McCabe, 1993; Pranter et al., 2009), coalbed distribution (Flores et al., 1984; Dubiel, 2000) and shoreface stacking (McCabe and Shanley, 1992; Johnson and Roberts, 2003) to enhance existing production and predictive modeling of natural resource accumulations. Sandstone bodies of these progradational settings have served as principal storage for hydrocarbon reserves, water supply and CO_2 sequestration (Johnson and Roberts, 2003; Cole and Cumella, 2005; Pranter et al, 2009). Therefore, formation of large-scale fluvial-marginal marine facies models is significant in predictions regarding sand body distribution, continuity, connectivity, degree of compartmentalization, and stacking patterns. The DFS concept may explain common patterns (e.g., up-section changes in net to gross, sand body thickness and architecture) observed in Cretaceous rock record examples. Depositional patterns and resulting facies distributions on distributive systems are very likely different from tributary stream systems, hence DFSs should be closely investigated (both modern and ancient) to construct basin-scale facies models.

Previous Work

Remote sensing analyses revealed DFS dominated fluvial sedimentation patterns in more than 700 purely continental sedimentary basins over wide climatic and tectonic regimes (Fig. 2; Weissmann et al., 2010, 2011). These authors noted that DFSs are developed in aggradational settings (sedimentary basins) with available preservation space (*sensu* Blum and Tornqvist, 2000), thus suggesting that DFSs make up a significant portion of alluvial successions in the rock record. Ancient examples of distributive systems were described in the Salt Wash and Westwater Canyon Members of the Jurassic Morrison Formation (Mullens and Freeman, 1957; Galloway, 1980;

Tyler and Etheridge, 1983), Oligocene-Miocene units of the Ebro Basin (Fig. 3; Hirst and Nichols, 1986), the Miocene Siwalik Group of Pakistan, and the Paleogene Willwood Formation of Wyoming (Willis and Behrensmeyer, 1995).

Some modern examples of DFS terminating in a marine setting include the Gilbert, Mitchell and Gascoyne Rivers of Australia, the Zambezi River of Mozambique, the Niger River of Nigeria, and the Mahanadi and Kaveri Rivers of India (Fig. 4). Except for the coastal plain portions (which are influenced by downstream tidal controls), most modern coastal DFSs appear to exhibit the same characteristics as purely continental systems. Relative to purely continental systems, few modern examples of DFS spanning the terrestrial to marine realm exist, as: 1) modern coastlines are presently flooded due to the high-amplitude Quaternary sea level fluctuations, 2) many rivers are incised into large valleys (Mississippi River) or incised into pre-existing coastal DFS deposits (Canterbury Plains of New Zealand, Texas Gulf coastal plain), and 3) many systems are anthropogenically-modified (Godhavari River of India), which conceals surface expressions and hinders natural channel behavior.

Incised valley systems (IVS) are 'fluvially eroded, elongate topographic lows' generally attributed to a fall in base level, which is considered to be sea level (Fisk, 1944; Shanley & McCabe, 1993; Zaitlin et al., 1994; Van Wagoner, 1995). The original model of valley fill architecture on the Lower Mississippi River Valley was proposed by Fisk (1944), whereby valley-cutting and sediment bypass occurred during periods of glaciation (sea level fall to lowstand), with subsequent incised valley aggradation and construction of delta plains during interglacial phases (sea level rise and highstand). Later work on the Texas Gulf Coastal Plain showed that this precise relationship between base level control and fluvial behavior is not so straightforward and upstream (climatic) factors also influenced erosional/depositional patterns (Blum, 1993; Blum and Valastro, 1994; Blum and Aslan, 2006).

The Campanian Williams Fork Formation represents an overall progradational package of coastal/alluvial plain fluvial deposits of northwest Colorado (Hettinger and Kirschbaum, 2002). Up-section trends in this unit include: 1) a transition from dominantly single-story channelbelt deposits encased in over-bank deposits to relatively structureless storeys amalgamated into thick sand bodies, 2) an overall increase in sand:mud ratio and sand body thickness, and 3) a decrease in overbank and coal deposits (Fig. 5; Cole and Cumella, 2005; German, 2006).

Methods

Characterization of facies distributions on modern coastal DFSs (Fig. 4) will be constructed to show the general upsection trends in channel form, grain size and facies proportions, which provide an alternative hypothesis to currently existing models (Shanley and McCabe, 1993; Little, 1997). From the proximal (landward) to coastal plain (basinward) portions of the DFS, satellite imagery will be utilized to delineate the following: geomorphic element distribution and proportion (i.e., active channel, abandoned channel, floodplain), changes in fluvial planiform and size, vegetative cover, and soil moisture. This will be conducted by visual delineation utilizing ArcGIS and Google Earth and digitization of depositional environment coverage. Results of geomorphic facies distributions observed from imagery analyses and fieldwork on multiple modern systems will ultimately be used to predict rock property distributions in ancient DFS deposits.

Facies mapping in the Williams Fork Formation will be conducted to compare observed facies distributions with two opposing paradigm models. To test these models, measured sections and photopans including stratal geometries and terminations, vertical facies stacking patterns, vertical grain size changes, paleosol and sandstone body extent and thickness, and key bounding surfaces from purely fluvial to marginal marine environments will be documented. In order to ascertain quantitative lateral and vertical changes in sand body dimensions and facies proportions, terrestrial LIDAR will be used in conjunction with photopan interpretation. Previously published literature on other potential Cretaceous coastal DFS candidates (e.g., John Henry Member of the Straight Cliffs Formation, the Blackhawk Formation,) will be used for interpretive purposes and as a comparison for lateral and vertical facies transitions.

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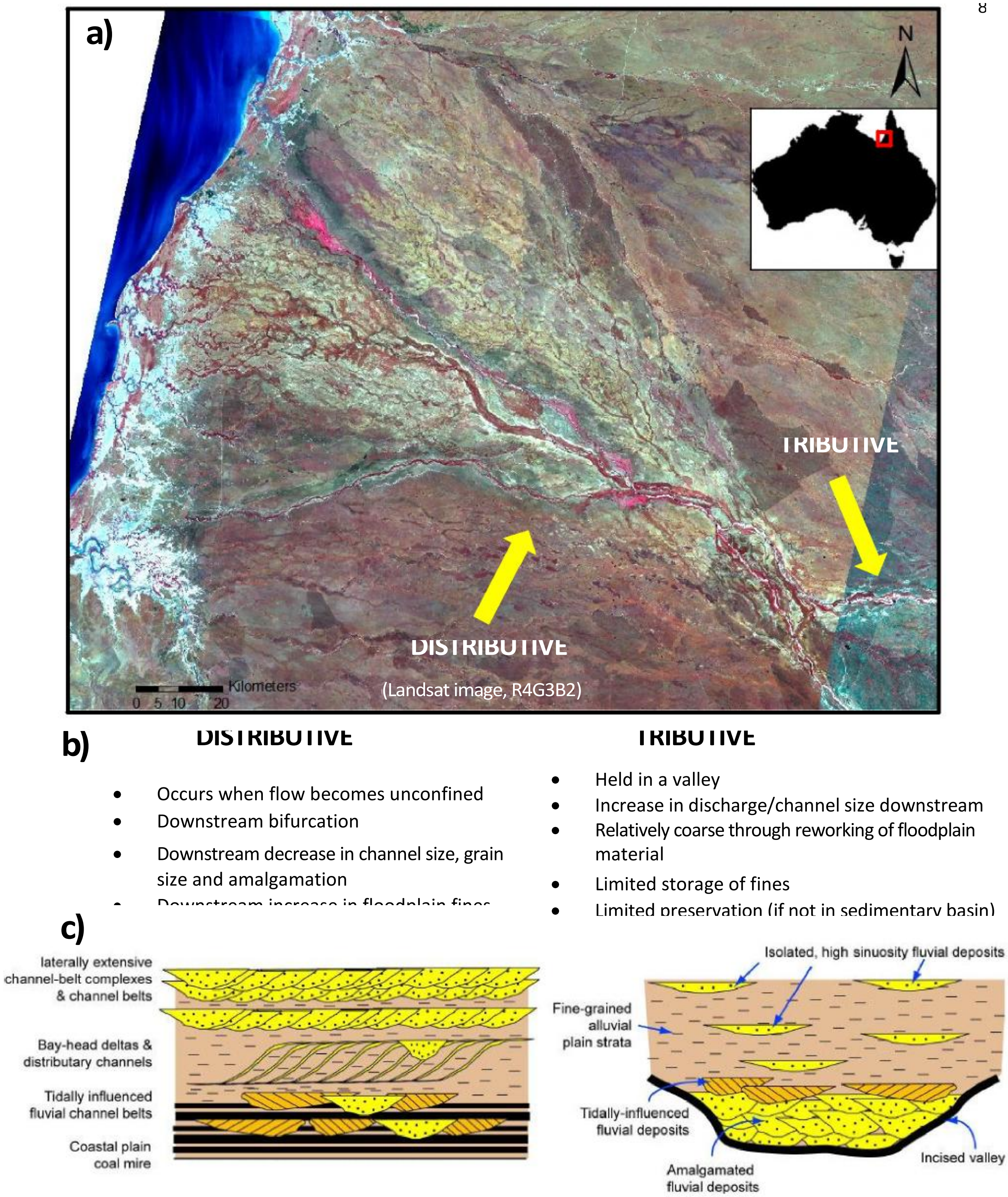

Figure 1: a) Landsat image of the Gilbert River DFS, fed by the tributive Gilbert and Einasleigh Rivers. Note the radiating channel pattern from the apex and decrease in channel size (due to bifurcation, evaporation, and/or infiltration) moving down-gradient. b) Common characteristics of tributive vs distributive systems (Shanley & McCabe, 1994; Hartley et al., 2010; Weissmann et al., 2010, 2011). c) Hypothesized vertical successions (not to scale). Tributive systems held in a valley will rework fines, creating a relatively coarse-grained succession. Once the valley is filled, the channel will migrate laterally, resulting in a higher proportion of floodplain material. Distributive systems will show an increase in sandbody thickness and grain size upsection, with a corresponding decrease in overbank fines as the system progrades (figure from Gallin et al., 2010; incised valley model modfied from Shanley & McCabe, 1994).

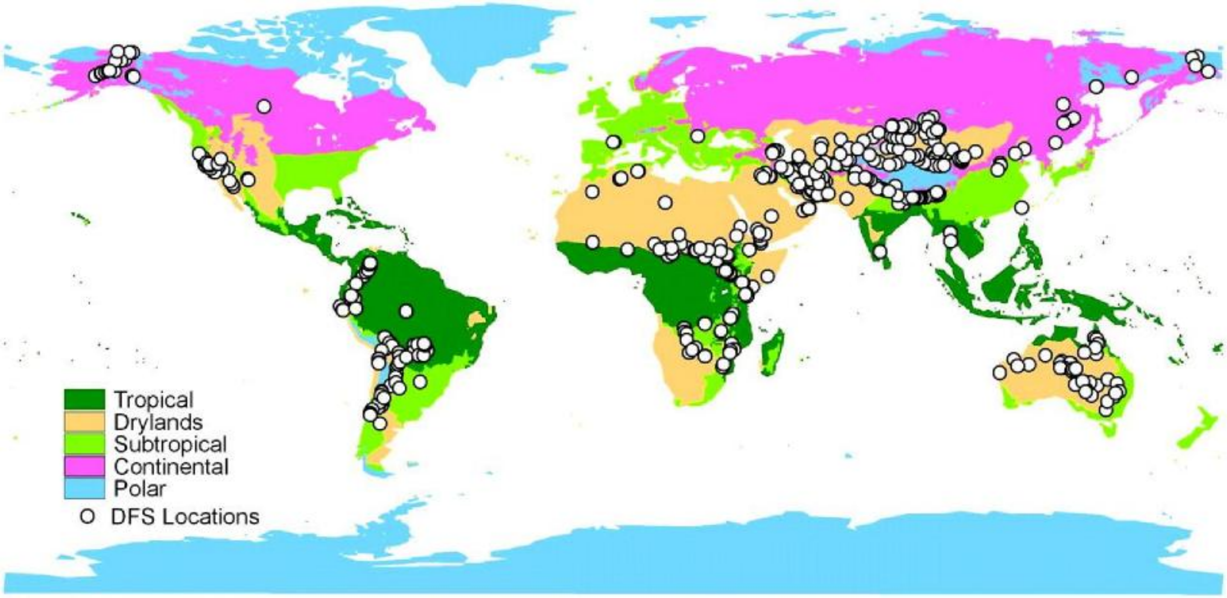

Figure 2: Locations of continental sedimentary basins on a simplified climate zone map (from Hartley et al., 2010; map from Kottek et al., 2006; sedimentary basin locations after Weismann et al., 2010).

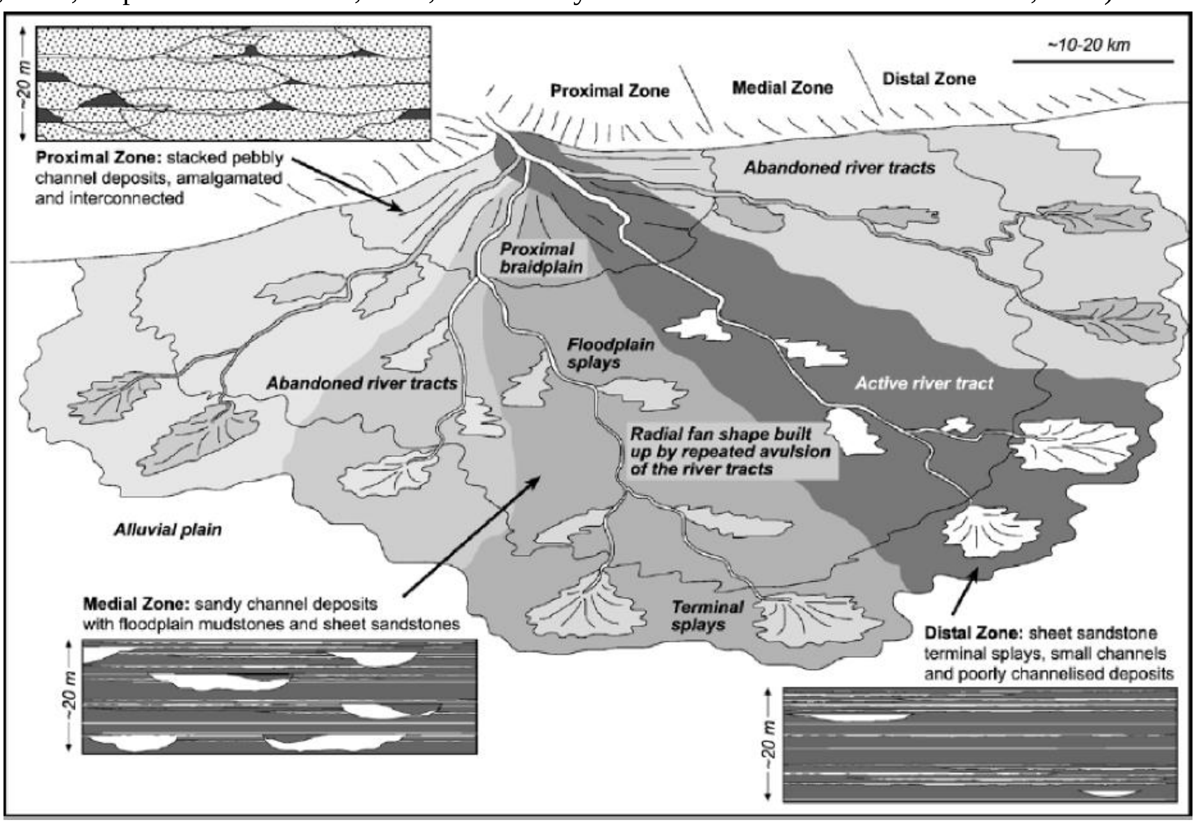

Figure 3: Conceptual DFS model showing proximal to distal channel trends and hypothesized vertical successions. This model was built from previous literature on DFSs in continental settings and new observations from the Ebro Basin (from Nichols & Fisher, 2007)

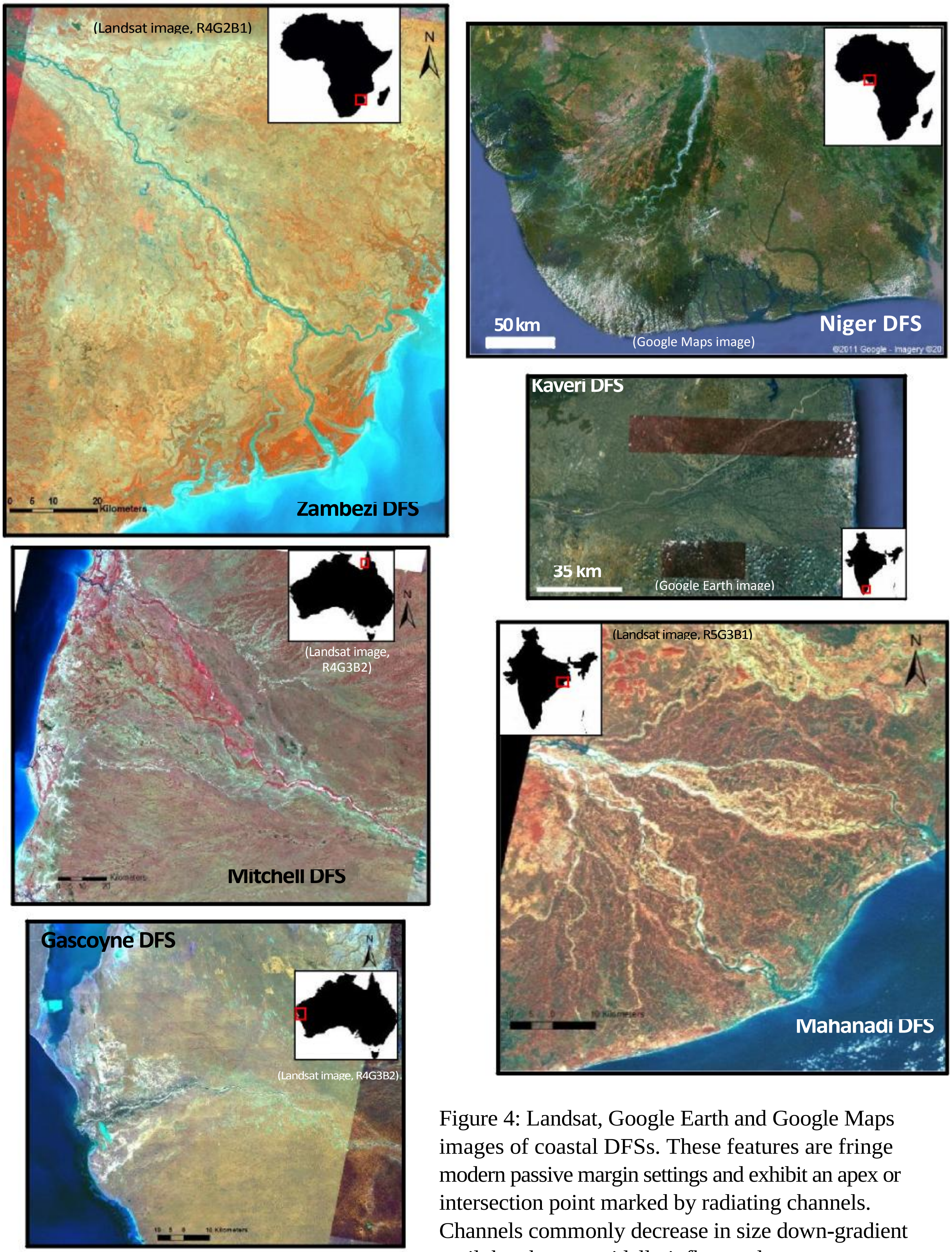

Figure 4: Landsat, Google Earth and Google Maps images of coastal DFSs. These features are fringe modern passive margin settings and exhibit an apex or intersection point marked by radiating channels. Channels commonly decrease in size down-gradient until they become tidally influenced.

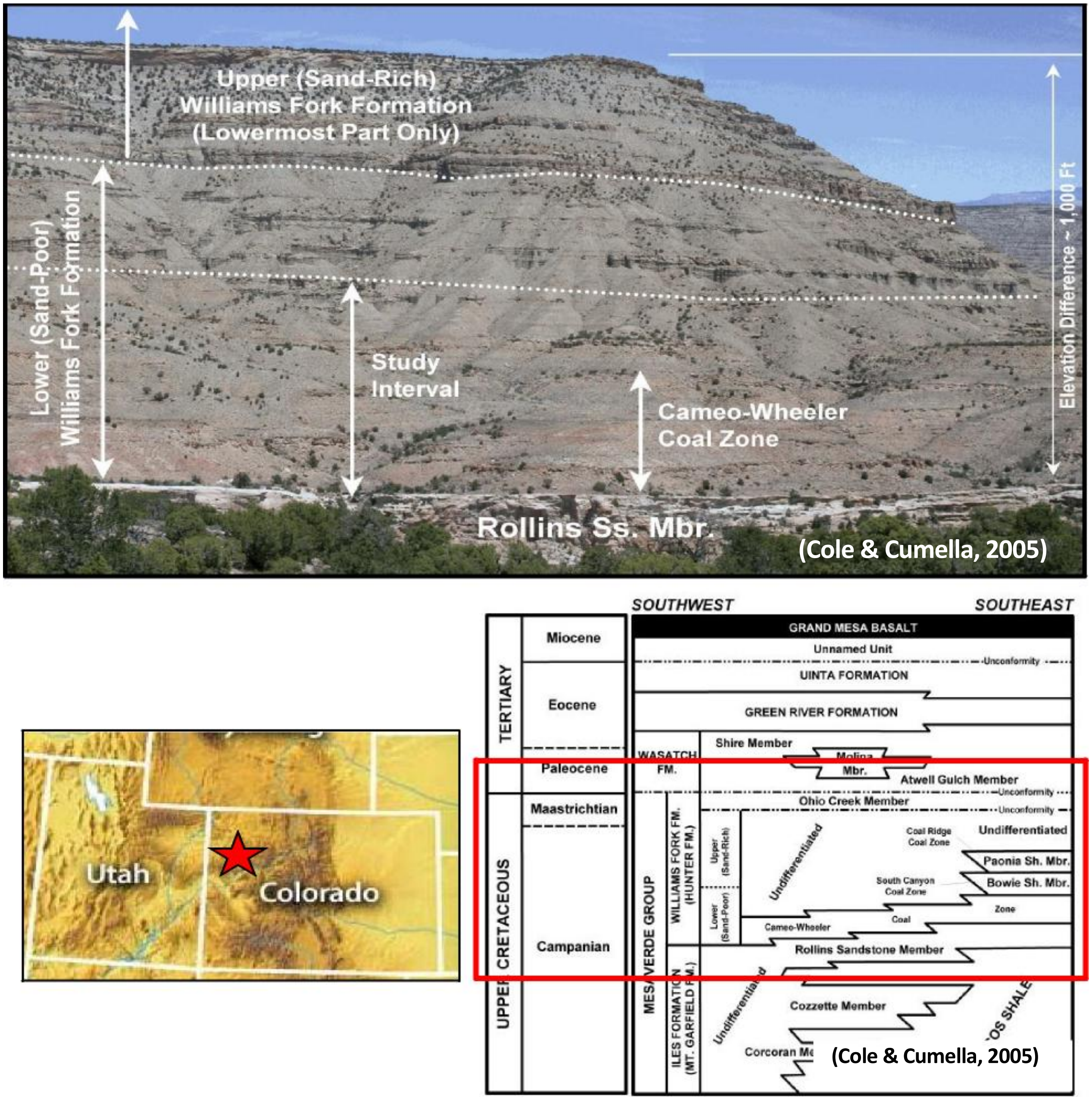

Figure 5: The Williams Fork Formation and Rollins Sandstone Member (Iles Formation) represent the final progradational sequence into the Cordilleran foreland basin, resulting from a Sevier highlands sediment source and accommodation created in the basin. This unit was mostly deposited before the onset of the Laramide orogeny, which created the present-day Piceance basin of northwest Colorado. Note the upsection trends in sand:mud ratio and channel size/amalgamation seen in outcrop.