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Basin Architecture and Evolution of Orphan Basin, Newfoundland

Michael McDonough*, Richard Evoy, David Hunter, Darryl Keiver,
Jock McCracken, Wayne Park, and Robin Slotboom
Petro-Canada Oil & Gas, 150 6th Ave SW, Calgary, AB T2P 3E3
mmcdonou@petro-canada.ca

ABSTRACT

The Orphan Basin comprises a series of Late Jurassic to Early Cretaceous rift half-grabens that are separated by linear basement ridges. Late Jurassic fault-driven subsidence and extension produced four Jurassic subbasins; the Western, Central, Southern and Eastern subbasins. Upper Jurassic growth strata and, locally Lower Cretaceous strata, are indicative of the timing of the principal phase of rifting. Local half-graben fill suggests that rifting may have begun as early as Triassic time. The Jurassic basin-bounding faults and their relay ramps have a direct spatial relationship to Jurassic sediment thicks, indicating a probable structural control of sediment input and distribution in Orphan Basin.

Five regionally mappable, seismically defined sequence boundaries have been identified. SB1 corresponds to a prominent set of very high amplitude reflections interpreted as the top of Paleozoic basement. SB2 has thin and irregularly shaped bodies characterized by discontinuous irregular to bleb-shaped reflectivity. Locally, strata overlying SB2 downlap onto a flat-lying detachment, suggesting evacuation of material at a thin salt layer. The most geologically reasonable correlation of SB2 is to the Upper Triassic-Lower Jurassic Argo salt in Jeanne d'Arc Basin. SB3 is jump correlated to the Orphan Basin from the sub-Cretaceous unconformity in the Flemish Pass Basin. In the Orphan Basin it forms a prominent, nearly continuous, high-amplitude peak lying at the top of a highly reflective package that is cut by numerous syn-rift faults, locally forming a low angle unconformity, particularly in the Central subbasin. In the Western subbasin, a detachment subjacent to the unconformity may be related to the presence of weak Tithonian source beds. SB4 is a fairly high amplitude event mappable from the Flemish Pass Basin, with a short jump tie across the Cretaceous "deep hole" adjacent to Flemish Cap, and then across the entire Orphan Basin. Well ties at I-78 and L-11 indicate a top Barremian age for SB4, which onlaps various basement ridges, and is broken by faults only on the flank of Flemish Cap. SB5 comprises a very high amplitude peak that is mappable on a continuous basis from Flemish Pass Basin across the entire Orphan Basin, and onto the Orphan Platform, corresponding to the Base of Tertiary Unconformity. Supra-unconformity strata show a westward increase in age from Pliocene strata overlying Albian in the Flemish Pass, to Miocene and Eocene strata in Orphan Basin. On the prominent linear basement highs, Eocene locally directly overlies Lower Cretaceous and perhaps older strata. SB5 is not observed to be broken by faulting in Orphan Basin.

The geometry of the Western subbasin is characterized by large displacement listric basin-bounding normal faults that produced the greatest amount of Jurassic accommodation space in the Orphan Basin. The thickest Jurassic sediment accumulation overlies a doubly plunging depression at basement level that controls the higher level structure, forming an overlying syncline at Jurassic level that inhibited generation of a trapping configuration. Trapping configurations developed only where basin-bounding faults have large displacement and are strongly listric, and the basement configuration permitted closure in the hanging wall as rollover anticlines. Locally, an irregularly shaped body attributable to salt is thickest in the core of a rollover structure. The proposed salt body has two extension faults that feed into its upper bounding surface forming an incipient reactive diapir that filled in the space created by extension . The eastern limb of the structure shows evidence of minor toe thrusting above a detachment in response to down-dip extension, presumably as a result of an active salt detachment. The basement displays a series of small culminations and depressions, but the average plunge is about 3-4^{o} south.

The Central subbasin comprises a series of horst and graben structures. The horsts are bounded by steeply diping faults, and tend to contain a thin package of Jurassic and Lower Cretaceous stratigraphy on them. The updip end of the larger fault blocks forms the trapping configuration for this play type. The Central subbasin graben generally displays a thick, gently dipping Jurassic section that is locally cut by faults that feed into a salt detachment. Local uplift related to toe thrusting in response to down dip extension above the salt may have removed some of the potential reservoir section.

The Southern subbasin was produced by south-side-down Jurassic growth faulting and subsequent rotation of a large basement cored fault block, the southern end of which forms a prominent basement cored ridge. This ridge forms the southern boundary of the Southern subbasin, and is truncated by a fault having a large amount of younger displacement. At the downdip end of the rotated system of fault blocks lies the potential source kitchen of the subbasin. The Southern subbasin is cut by a series of north-south trending faults that compartmentalize the larger structure.

The Eastern subbasin is characterized by large displacement east vergent listric normal faults that acted as basin-bounding faults on the flank of the Flemish Cap. Listric faulting above a mid-crustal detachment led to a large 30-35^{o} dipping fault panel that is cut into a number of smaller blocks by subsidiary faulting. The downdip end of the panel lies in the oil window, forming a prospective source kitchen proximal to the potential updip reservoirs. The updip end of the panel is probably eroded at the sub-Cretaceous Unconformity due to the large amount of fault block rotation.

In the Early Cretaceous, the Orphan Platform was cut by a series of north-trending west-side-down listric extension faults that root in the mid- to lower crust, producing a series of north-south linear basement ridges and adjacent subbasins that are separated from the Jurassic subbasins by a basement ridge. Early Cretaceous subbasins on the Orphan Platform have a north-south trend that may be inherited from earlier Jurassic precursor structures. The Blue H-28 subbasin is filled by Hauterivian to Campanian strata, with possibly a thin and partially eroded epicontinental Jurassic? sequence overlying a highly rotated basement block. The area of greatest Early Cretaceous fault-driven subsidence in the Orphan Platform lies to the east of the Blue subbasin, and west of the area of Jurassic subbasin development. This subbasin also displays a rotated basement block with a thin partially eroded cover sequence interpreted to be Jurassic. Similarly, the southern margin of the Southern subbasin is bounded by a large displacement fault set that displays mainly Early Cretaceous displacement and growth. These faults created Neocomian accommodation that resulted in east-west trending Early Cretaceous subbasins that rim the Southern Jurassic subbasin.

The most significant Cretaceous fault-driven subsidence occurred between the Central and Eastern Jurassic subbasins. No Triassic or Jurassic reflection signature is observable there, and the acoustically transparent material above basement resembles the Cretaceous section. Generation of this feature is correlated to the time of formation of oceanic crust on the Flemish and Galician margins. Crustal thinning and the rise of the Moho to the mid-crustal detachment level in the Eastern Orphan Basin was arrested by the formation of Early Cretaceous oceanic crust to the east of the Flemish Cap.

The pattern of greatest Early Cretaceous extension and accommodation space development exhibits a marked spatial partitioning to areas outside of the principal zone of Jurassic rifting in the Western, Central and Southern subbasins. Minor Early Cretaceous accommodation space developed in the Western and Southern Jurassic subbasins as a continuation of Jurassic rifting into the Cretaceous, but the principal Early Cretaceous accommodation space developed to the west and south of the Jurassic subbasins and in the Flemish Pass Basin. These spatial and temporal changes of accommodation space development occurred because the Early Cretaceous basin-bounding faults dip away from the main Orphan Jurassic subbasins. Thus, the area of crustal weakening and rifting processes in Orphan Basin broadened outward through time, but had little effect on the preexisting Jurassic subbasins because the Jurassic detachments no longer received significant displacement. The stretching capacity of the crust may have become impaired by a rapid decay of Jurassic heat flow, inducing the mid-crustal Jurassic detachments to work harden and forcing the displacement to be transferred to outlying areas in Early Cretaceous time.

Relative to an assumed Pre-Mesozoic thickness of 32 km, the crust in the Orphan Basins has been thinned by a factor of 3 to 8 times. □-factors of less than 1.5 occur over a widespread area in the Orphan Platform and Flemish Cap, indicating that these areas have undergone very little crustal thinning and therefore experienced minor extension compared to the principal areas of basin development. The most severe thinning in the Orphan Basin occurred west of the Flemish Cap where the crust thins to less than 5 km leading nearly to the formation of oceanic crust. With the exception of this area, relatively few small displacement faults cut the Barremian to Base Tertiary interval in the Orphan Basin. Therefore, Late Cretaceous subsidence is interpreted to be largely non-fault-related and thermal in character.

Continued subsidence of the Orphan Platform in Tertiary times does not appear to have been fault driven, but yielded a cover with as much as 7 km of Tertiary strata. This may have been in response to a reorganization of oceanic extension vectors in the early Tertiary. In the Orphan Basin, the Priabonian Unconformity onlaps eastward onto highs formed by rotated fault blocks of Jura-Cretaceous strata on the margin of Flemish Cap, and westward, nearly onto the basement highs of the Western subbasin. Thus, Early Tertiary subsidence in Orphan Basin is confined to the area of greatest syn-rift extension. The spatial relationship of continued Tertiary subsidence to deep-seated syn-rift faults is clear, however, no faults can be demonstrated to have driven this subsidence.

Restored crustal sections across the Orphan Basin indicate a number of significant results: 1) upper crustal brittle extension during Jurassic to Early Cretaceous rifting induced a relatively modest 40-50 km of horizontal displacement in the Orphan Basin; 2) most of the extension roots into a mid-crustal detachment level at approximately the same level as the elevated Moho beneath the Cretaceous “deep hole”; 3) restoration of the large displacement easterly vergent faults associated with the “deep hole” yield a large basement high with thin Jurassic cover linking the Flemish Cap to the basement highs on the east side of the Central subbasin; 4) significant syntectonic erosion of basement fault blocks and their bounding faults probably occurred in the Early Cretaceous; and 5) ductile extension at lower crustal levels beneath the mid-crustal detachment(s) appears to have been greater than the upper crustal 50 km of extension. A sixth potential result of the restoration is that ductile evacuation of lower crust may have created space for upper crustal extension, allowing deep-seated basin formation to occur without a tremendous amount of horizontal displacement at the top Jurassic level. A speculative cause of the “bottom falling out” may be that the crust was pre-conditioned for failure by preexisting Paleozoic compressional structures that were readily reactivated.