2857031 The Eocene Elko Basin and Elko Formation, NE Nevada: Paleotopographic Controls on Area, Thickness, Facies Distribution, and Petroleum Potential

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Abstract

Based on published and my ages, the Elko Basin developed at ~46 Ma. Sediments that make up the Elko Fm accumulated in the basin until ~38 Ma; deposition ended diachronously, oldest to the southwest where input from the Robinson Volcanic Field (Piñon Range) overwhelmed other sources. Published depictions of the Elko Basin have ranged from large rectangular areas (~17,000 km2, present day) to a contiguous area (~8000 km2) with a partly dividing intrabasin high in the Adobe Range. The basin probably resulted from early extension of the Ruby Mts metamorphic core complex, although the amount of early extension is debated. All depictions effectively assume that the basin was continuous and developed on flat topography.

In contrast, the distribution of 45-40 Ma ash-flow tuffs show that they were channelized into major east-trending paleovalleys. E.g., the 40.2 Ma tuff of Big Cottonwood Canyon is preserved in three curvilinear belts between its source caldera in the northern Tuscarora Mts eastward 180 km to the Pequop Mts. I interpret this distribution to reflect flow and deposition in three east-draining paleovalleys. The caldera is within the NW part of the previously interpreted Elko Basin, and the Pequop Mts in or east of the basin. If the tuff had erupted onto the interpreted large, flat, continuous basin, it would have spread out as an aerially restricted, proximal sheet. The tuff's actual distribution precludes such a large, continuous basin. I interpret the Elko Basin to have developed initially as separate depocenters where northwest-dipping normal faults cut paleovalleys. Individual depocenters were generally separated by topographically high interfluves (as much as 1.5 km relief) but may have been hydrologically connected intermittently during basin evolution. The thickest, especially lacustrine, potentially hydrocarbon-generating sediments accumulated and are preserved in these depocenters. My interpretation predicts considerably thinner deposits over interfluves, consistent with observation. Sedimentary structures in Elko Fm lacustrine deposits indicate generally shallow water deposition, so sedimentation kept up with basin subsidence. This interpretation reduces the potential total volume of source rocks in the Elko Basin but suggests the possibility of additional prospective basins along known paleovalleys. This interpretation also has implications for the distribution of sediments and source rocks in other intermontane basins of the western US.

The "Nevadaplano" and Paleodrainages of the Great Basin

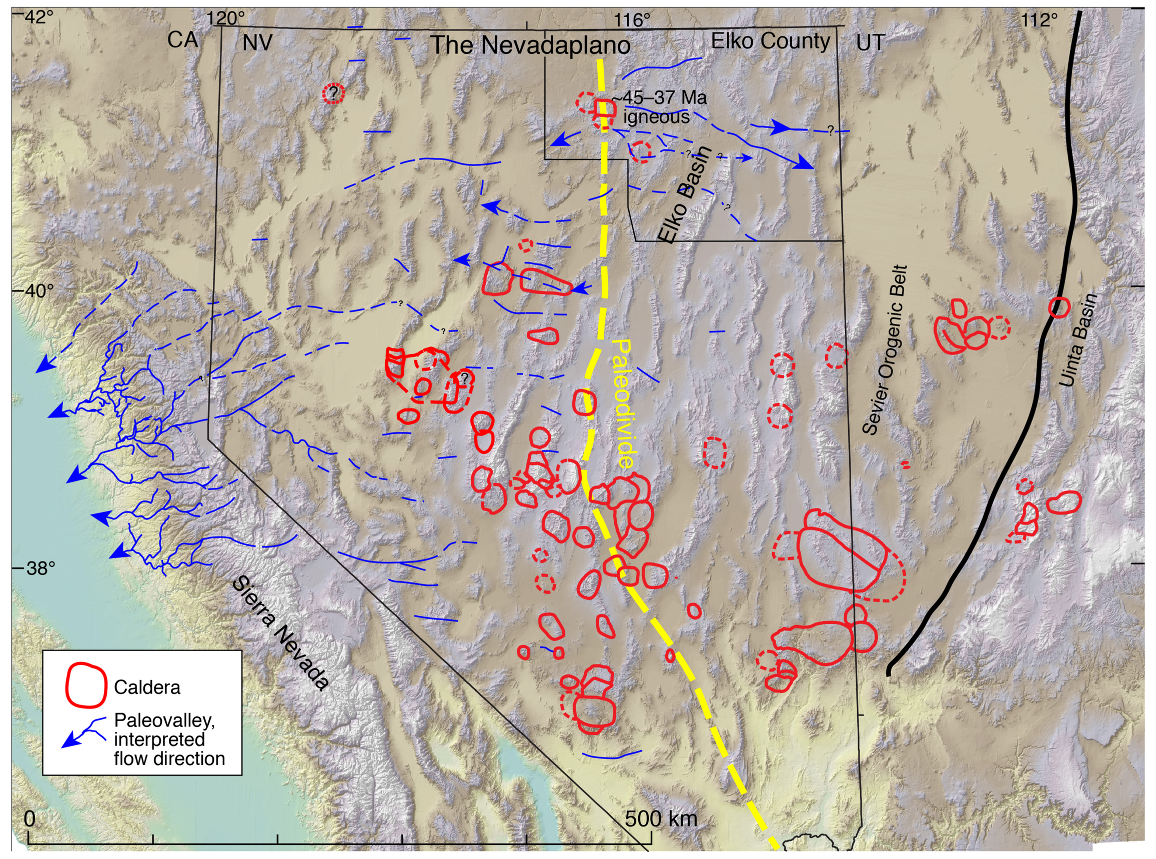


Fig. 1. The Elko and other intermontane Paleogene sedimentary basins in NE Nevada have long been of scientific interest. Interest has greatly increased with Noble Energy's demonstration of significant hydrocarbon resources in the Elko Basin. However, the timing, geometry, continuity, and tectonic origin of basins have been interpreted very differently, exemplified by the Eocene Elko Fm and Elko Basin (Figs. 2, 3. Solomon et al., 1979; Solomon, 1992; Satarugsa and Johnson, 2000; Haynes, 2003; Henry, 2008; Henry et al., 2011; Smith et al., 2017). Much of this variability stems from a lack of appreciation of major, pre-Elko Fm topography, first(?) recognized in NE Nevada by Charles "Chuck" Thorman (e.g., Brooks et al., 1995). Before dismembered by middle Miocene and younger extension, the Nevadaplano, a topographic high resulting largely from Mesozoic contraction (DeCelles, 2004), was cut by a series of deep (up to ~1.5 km), wide (6 to 8 km) paleovalleys that drained eastward and westward from a paleodivide that ran roughly north-south through east-central Nevada (Henry, 2008; Henry et al., 2012; Cassel et al., 2014). The paleovalleys drained westward to the Pacific Ocean and eastward to the Uinta Basin and its remnants. Elevations along the paleodivide probably reached 4 km (Cassel et al., 2014).

Geology of Elko County, Nevada

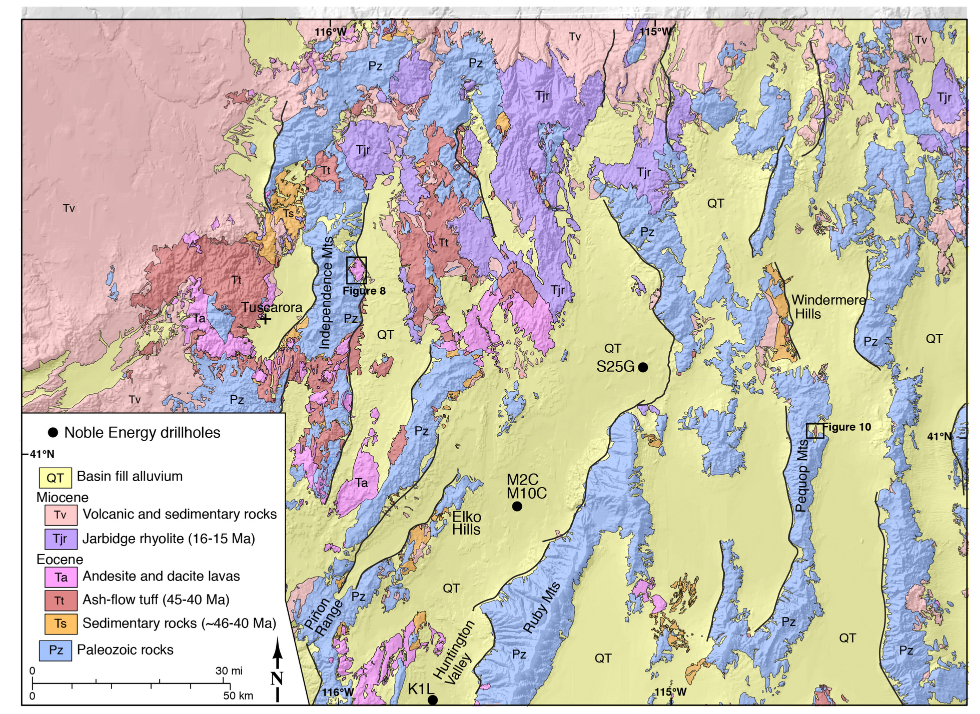


Fig. 2. The Eocene Elko Fm (Ts above) consists of conglomerate, lacustrine limestone, and significant oil shale that began to be deposited at least by 46 Ma (Solomon et al., 1979; Haynes, 2003; Smith et al., 2017) and mostly predate major volcanism beginning around 40 Ma in the Elko basin area and resulting from rollback of the formerly shallow Farallon slab (Ressel and Henry, 2006). The Elko Fm is commonly interpreted to have accumulated in half grabens related to early development of the Ruby Mts metamorphic core complex (Haynes, 2003; Howard, 2003; Hickey et al., 2005; Henry, 2008), but this extension is variably interpreted as minor (Henry, 2008; Colgan and Henry, 2009; Colgan et al., 2010) or major (McGrew et al., 2000). See Henry et al. (2011) for comprehensive presentation of both interpretations.

Previous Interpretations of a Large, Contiguous Elko Basin

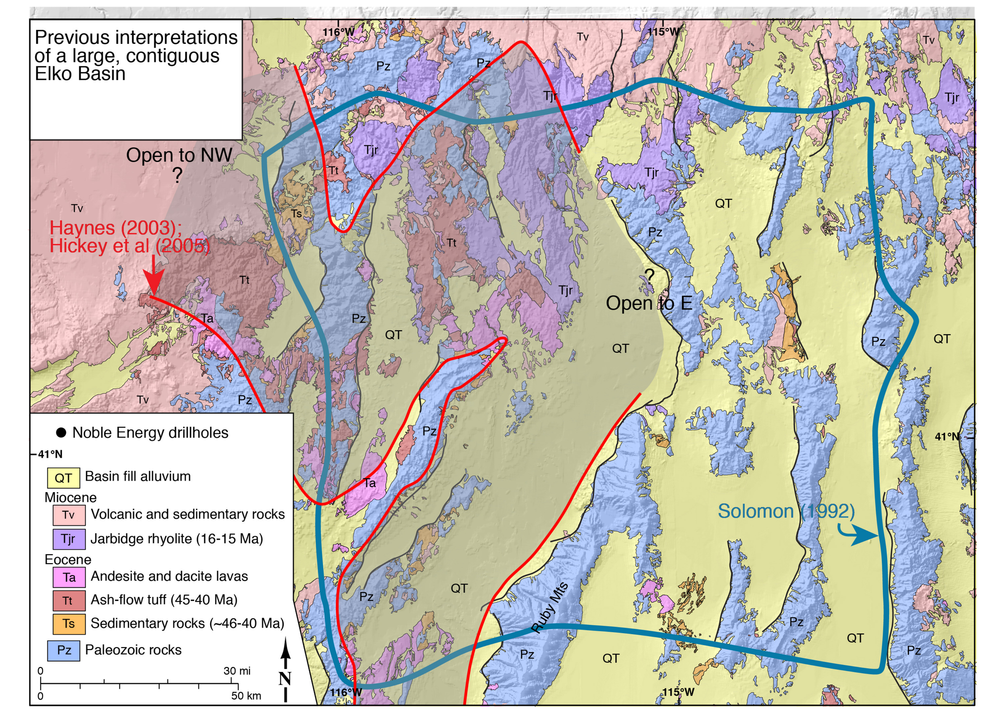


Fig. 3. Most previous interpretations made the unstated assumption that the Elko Basin developed on flat topography, which effectively led to a derivative interpretation of a large, contiguous basin (Solomon, 1992; Haynes, 2003; Hickey et al., 2005). Further, dispersed outcrops of Eocene sedimentary rocks were assumed to have been deposited in a connected basin, although Solomon (1992) recognized that many were not.

Paleovalleys Interpreted from Distribution of Eocene Sedimentary and Volcanic Deposits

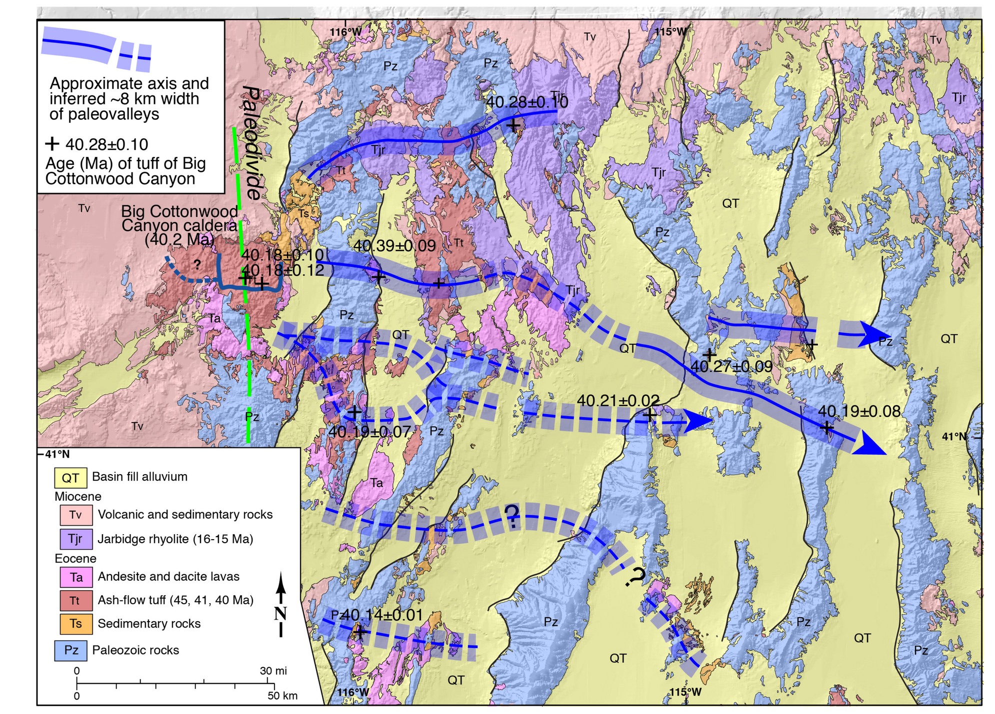
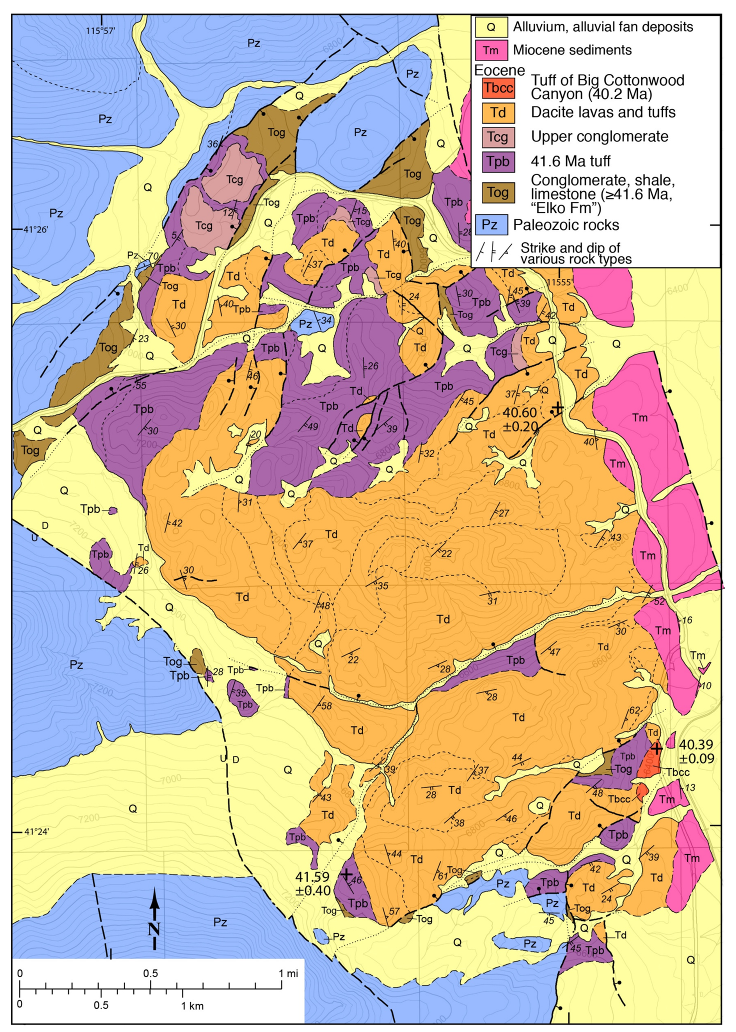


Fig. 4. The distribution of Eocene sedimentary and volcanic deposits, especially the 40.2 Ma tuff of Big Cottonwood Canyon, demonstrate the presence of several major east-draining paleovalleys. The Eocene sedimentary rocks are thickest in, and partly restricted to, narrow belts along the paleovalleys (Henry, 2008; Smith et al., 2017). The tuff erupted from a caldera near Tuscarora and flowed down these paleovalleys at least as far as the Pequop Mts and eastern Windermere Hills (Figs. 5-8). A tuff erupting onto flat topography, either an undissected high plateau or a series of widespread basins resulting from extension, would have spread out and flowed a much shorter distance (Henry, 2008). This sedimentary and tuff distribution precludes the Elko Basin existing near Tuscarora or being anywhere near as large and contiguous as depicted in Fig. 3.

Paleovalley, Eastern Independence Mts



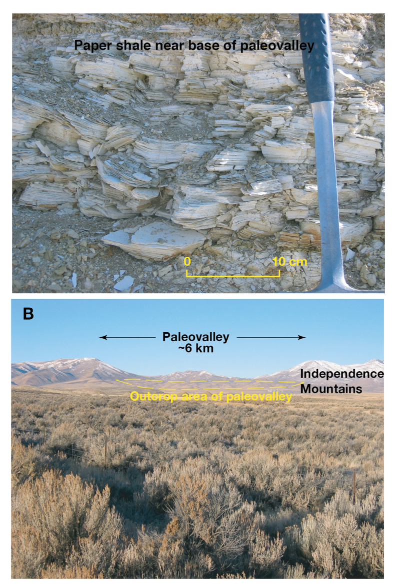
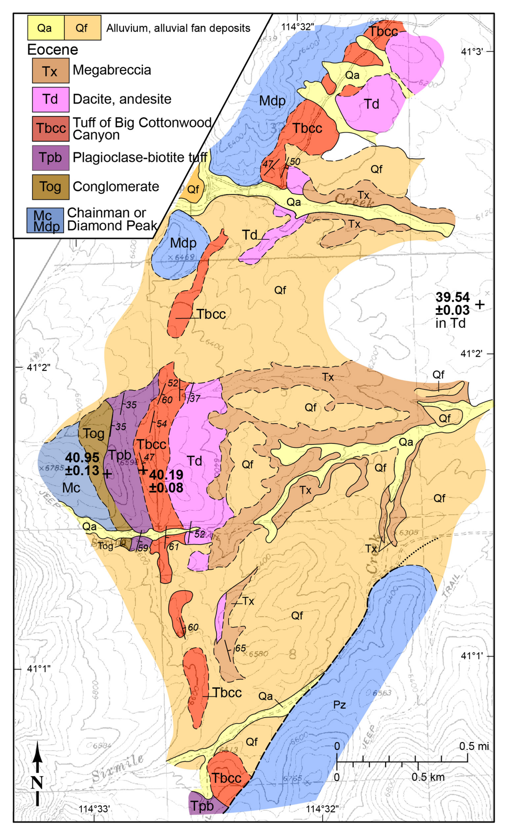


Fig. 6. A. Eocene paper shale (probably oil shale) containing metasequoia fragments. B. Topographic expression of the paleovalley in the east-tilted Independence Mts (sort of "up-plunge" view).

Figs. 5-8. The Eocene sections in the eastern Independence Mts (Muntean and Henry, 2003) and at Nanny Creek in the Pequop Mts (Brooks et al., 1995; Henry and Thorman, 2015) illustrate the distribution and variable character and thickness of Eocene sedimentary deposits and distribution of the tuff of Big Cottonwood Canyon. Eocene rocks in the eastern Independence Mts are restricted to two paleovalley segments incised into Paleozoic rocks. Eocene sedimentary rocks consist of poorly exposed, coarse conglomerate, lacustrine limestone, and paper shale (Fig. 6A) totaling about 60 m thick. These are overlain by a 41.6 Ma ash-flow tuff, a thick sequence of locally derived dacite lavas, and the 40.2 Ma tuff of Big Cottonwood Canyon. The broad cut in the Independence Mts occupied by Eocene deposits illustrates the wide, shallow character of paleovalleys (Fig. 6B).

Paleovalley, Nanny Creek, Pequop Mts



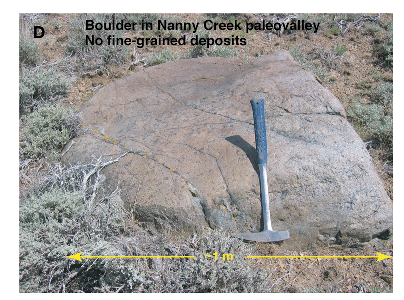


Fig. 8. Well-rounded, fluvially transported boulder in base of Nanny Creek paleovalley.

Fig. 7, 8. The Eocene section at Nanny Creek consists of conglomerate, exposed only as a boulder lag, ≤40 m thick, overlain by a 41.0 Ma tuff, overlain by the 40.2 Ma tuff of Big Cottonwood Canyon, overlain by a thick sequence of 39-40 Ma dacite to andesite lavas. Boulders are well rounded, indicating significant fluvial transport (Fig. 8), and lacustrine sedimentary rocks are absent. Rocks that make up the base or wall of the paleovalley pass from Mississippian Chainman Shale in the deepest part to Diamond Peak Formation to Permian Pequop Fm in the northernmost wall, which indicates the paleovalley was more than 1 km deep. The Eocene rocks wedge out against the wall upward, with conglomerate only in the deepest, middle part of the paleovalley.

Paleovalleys superposed on Thickness Trends of Smith et al. (2017)

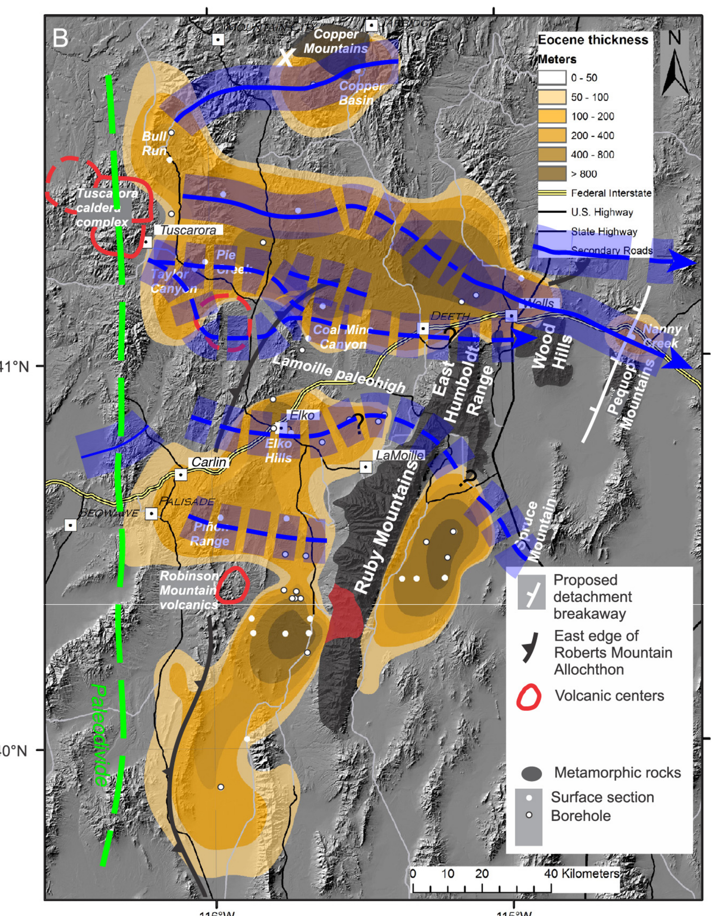
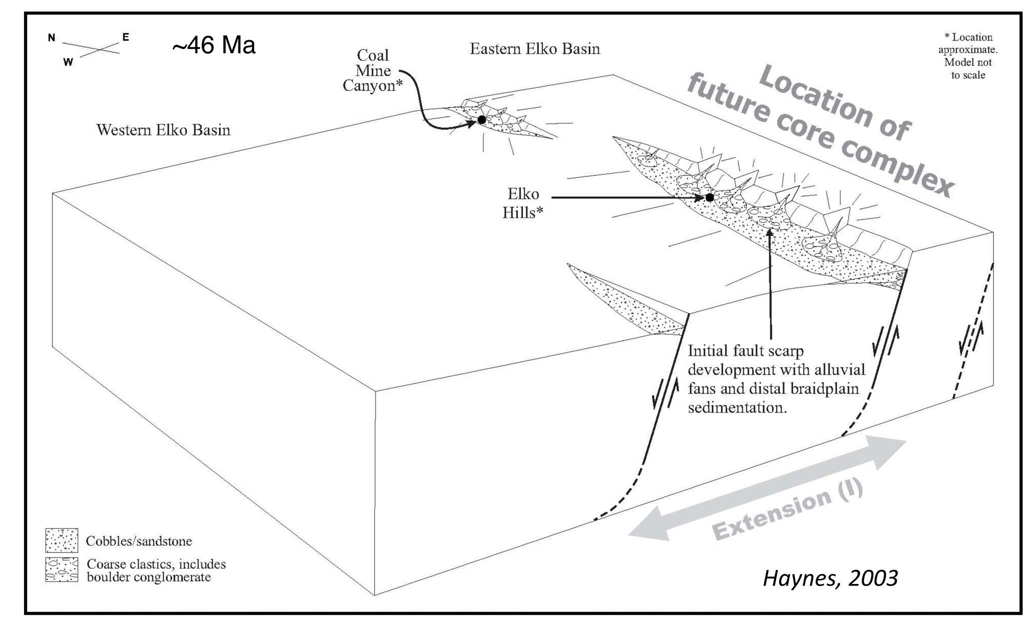
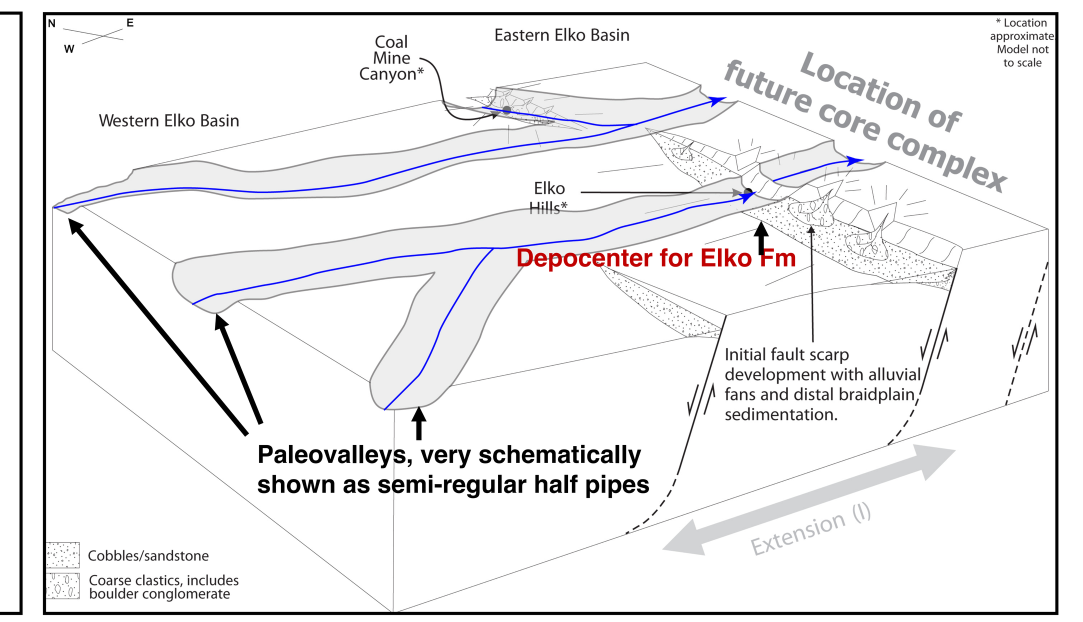
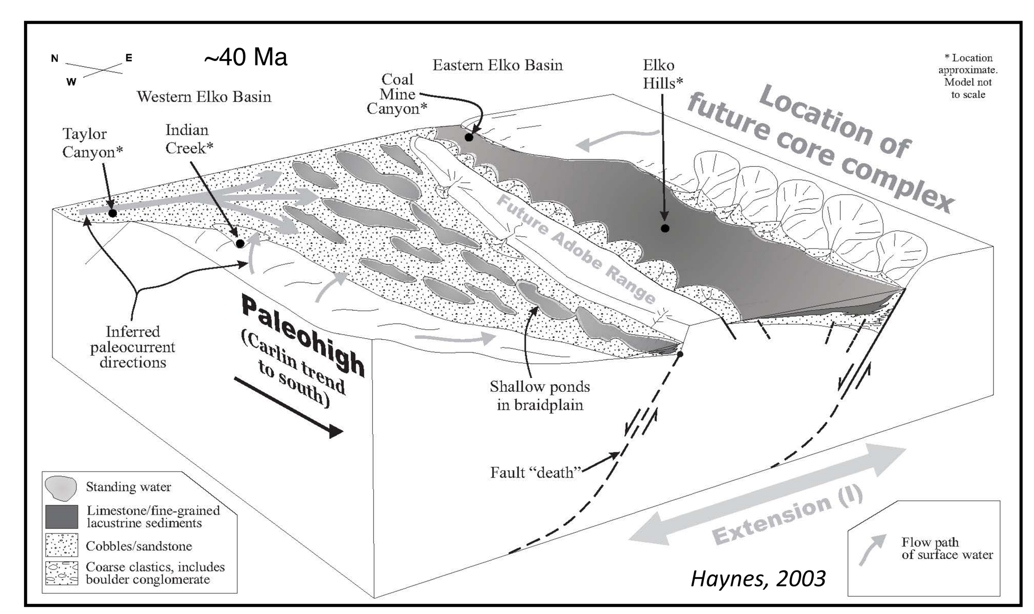


Fig. 9. Moreover, surface and subsurface data show that Eocene deposits are thickest along the east-trending paleovalleys (Smith et al., 2017; Satarugsa and Johnson, 2000). We differ somewhat from Smith et al. (2017) in interpreting much lesser thicknesses between separate paleovalleys, for example in the Independence Mts and between the Elko Hills and Pinon Range.

Revision of the Haynes (2003) Model with Paleotopography and Paleovalleys







Discussion: My favored interpretation is that the Elko Fm accumulated mostly in a gently east-tilted half graben along what is now the western edge of the Ruby Mts metamorphic core complex. The NNE-striking, northwest-dipping fault there was paralleled by smaller displacement faults to the northwest, demonstrated by thin Eocene sedimentary rocks in the Independence Mts (Fig. 5). Faulting was either minor to the east, or a fault was significantly east of the Nanny Creek paleovalley so that negligible sediments accumulated beneath the tuff of Big Cottonwood Canyon in outcrop (Fig. 7). Eocene sedimentation continued in the paleovalleys until basin subsidence ended and/or volcanic input overwhelmed. The paleovalleys continued to exist as significant topographic features after Elko Fm deposition because the tuff of Big Cottonwood Canyon was able to flow long distances in the paleovalleys (Figs. 4, 7). However, the apparent absence of the tuff of Big Cottonwood Canyon around the Elko Hills may indicate that a lake remained there, so that a pyroclastic flow spread out and became water laid and difficult to recognize. At this time, I do not know whether this tuff shows up in Noble Energy M2C or M10C drill holes (Fig. 2).

My interpretations partly correlate with and partly modify those of Haynes (2003) and Smith et al. (2017). The Haynes (2003) model of Elko Fm deposition assumed that faulting beginning about 46 Ma cut through flat topography. Instead, the region was cut by numerous paleovalleys, shown very schematically here as semi-regular half pipes. Fault displacement and minor eastward tilting created major depocenters in the hanging wall along the paleovalleys. Individual depocenters were separated by topographically high interfluves but may have been hydrologically connected intermittently during basin evolution. Deposits are thickest near the fault and thin both laterally onto adjacent interfluves and up valley. Shallow-water depositional features of oil shale in Noble Energy's K1L drillhole in Huntington Valley indicate deposition kept up with subsidence. Total thicknesses of no more than 1 km of Elko Fm would require only 1 km of fault displacement, which is part of the evidence for minor Eocene extension (Henry, 2008; Colgan and Henry, 2009; Henry et al., 2011).

Smith et al. (2017) also recognize the presence of paleodrainages but state "Drainage disruption and ponding of surface waters likely resulted from one or more slab removal-related processes" (the formerly shallow Farallon slab) and "lack evidence for major surface-breaking normal faults". They cite absence of growth strata or clasts sourced from the footwall (which, by my interpretation, would have been the uppermost Ruby Mts) and contrast those characteristics with those of middle Miocene and younger extensional basin deposits (e.g., Colgan et al., 2010). However, Elko Fm crops out in only one small area along the west front of the Ruby Mts (Smith and Howard, 1979), the presumed footwall, and clasts in conglomerate there are only identified as Paleozoic. The minor extension and tilting compared to Miocene extension means that fanning of dips should not be expected. Additionally, clasts in exposed basal conglomerates throughout the region are what were being transported along paleovalleys from the west. Greater exposure of Elko Fm near the west edge of the Ruby Mts would be nice but is beyond my control.

On one hand, my interpretation restricting the distribution and volume of Elko Fm rocks compared to previous work suggests there is not a single Elko Basin as depicted previously, and a lesser total petroleum potential in the area of those previous depictions. On the other hand, as pointed out by Solomon (1992), similar Eocene deposits occur widely in eastern Nevada, which may increase ultimate potential. Regardless, exploration needs to consider where, and how voluminous, such rocks are.

Many more aspects of development of the Elko Basin could be discussed but, more critically, need to be examined and evaluated.

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