CHAPTER 8

REVISED MAPPING OF THE UPPER JURASSIC NAKNEK FORMATION IN A FOOTWALL SYNCLINE ASSOCIATED WITH THE BRUIN BAY FAULT SYSTEM, CHINITNA BAY REGION, WESTERN COOK INLET, ALASKA

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INTRODUCTION

The Alaska Division of Geological & Geophysical Surveys (DGGS) is engaged in a multi-year investigation of the petroleum geology of the Cook Inlet region in southern Alaska. The Cook Inlet forearc basin has a long history of oil and gas production, and resource assessments indicate that significant potential remains for additional hydrocarbon discoveries (Stanley and others, 2011; LePain and others, 2013). Recent DGGS-led work includes detailed 1:63,360-scale geologic mapping as well as topical structural and stratigraphic studies (Gillis, 2013, 2014; Wartes, 2015; Herriott, 2016 [this volume]). These types of data provide important constraints on the evolution of the petroleum system and reduce exploration risk. This brief report summarizes new geologic mapping of Jurassic rocks in the Chinitna Bay region of western Cook Inlet (figs. 8-1 and 8-2) and offers additional insight into the structural evolution of the basin margin.

PREVIOUS WORK

The Bruin Bay fault system is a major structural boundary in western Cook Inlet, separating Jurassic magmatic arc and associated rocks from Middle to Upper Jurassic forearc basin strata (fig. 8-1; Detterman and Hartsock, 1966). Earlier mapping noted equivocal piercing points, suggesting the fault system was dominated by sinistral strike-slip motion with estimates of offset ranging from ~20 to 65 km (Detterman and Reed, 1980). More recent reconnaissance studies by DGGS recorded slip indicators on faults suggesting a complex mix of strike-slip and dip-slip motion (Gillis and others, 2013). Subsequent detailed studies provided robust kinematic analysis of fault surfaces, documenting at least two fault populations that record reverse and strike-slip deformation; the apparent oblique polyphase slip history may partly reflect variations in the strike of the fault (Betka and Gillis, 2016 [this volume]) and/or discrete episodes of faulting under different regional stress orientations (Betka and Gillis, 2014).

NEW MAPPING

During summer 2015 DGGS conducted detailed geologic mapping of the region between Chinitna Bay and the Johnson River (fig. 8-1). The southern part of the map area between Chinitna Bay and East Glacier Creek was recognized as important due to the potential to resolve understanding of structural and stratigraphic details in the immediate footwall of the Bruin Bay fault. The new mapping (fig. 8-2A) shares a broadly similar pattern with Detterman and Hartsock (1966), although the mapped stratigraphy and structures in the footwall of the fault are different in several notable aspects (fig. 8-2). We did not recognize the three folds (anticline–syncline–anticline) depicted in the earlier mapping (fig. 8-2B). Instead, aerial reconnaissance and several mapping traverses established the presence of a single, large overturned footwall syncline (figs. 8-2A and 8-3). Small-displacement, out-of-syncline backthrusts are present near the core of the fold (fig. 8-4), consistent with space problems associated with an increase in bed curvature during progressive folding (Mitra, 2002). Approximately 3 km east of the syncline our mapping defined a broad, relatively symmetric anticline (figs. 8-2A and 8-5), generally in agreement with Detterman and Hartsock (1966).

Three members of the Upper Jurassic Naknek Formation are present in the footwall syncline; the basal unit (lower sandstone member) has distinctive light-gray-weathering lithofacies that can be readily mapped southeastward to well-exposed coastal cliffs overlooking Chinitna Bay (fig. 8-3; Wartes and others, 2015). The overlying Snug Harbor Siltstone Member forms much of the exposed stratigraphy outlining the syncline (figs. 8-2 and 8-3). This unit is heterolithic, typical of the Snug Harbor in the region, including interbedded tabular, very-fine sandstone and siltstone with rare beds of poorly organized pebble conglomerate (see also Herriott and Wartes, 2014). Sole marks and ripple cross-lamination are uncommon, but provide useful stratigraphic top indicators, confirming the locally overturned nature of the western limb of the syncline. The Pomeroy Arkose Member is limited to a few tens of meters of very poorly organized boulder conglomerate preserved in the core of the syncline (figs. 8-2, 8-3, and 8-4). Similar anomalously coarse-grained facies are present in the Pomeroy on the southwestern Iniskin Peninsula (Wartes and others, 2013; Detterman and Hartsock, 1966).

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CORRELATION WITH OTHER STRUCTURES IN THE REGION

The asymmetry of the footwall syncline strongly suggests it formed in response to top-to-the-east reverse motion on the Bruin Bay fault. This geometry is very similar to a prominent footwall syncline documented south of the Iniskin Peninsula, at Ursus Head (fig. 8-1; Gillis and others, 2013; Betka and Gillis, 2015), as well as other newly mapped east-vergent footwall synclines to the north near Red Glacier and the upper Johnson River areas (fig. 8-1; Betka and Gillis, 2016). Footwall shortening appears to be principally concentrated adjacent to the Bruin Bay fault at each of these locations, with relatively gentle dips basinward of the tight footwall synclines (for example, fig. 8-2A).

The Fitz Creek anticline on the Iniskin Peninsula (figs. 8-1 and 8-6) has long been recognized as an exploration target due to several oil and gas seeps along the crest of the structure (Detterman and Hartsock, 1966). This fold is in a broadly similar position to the anticline mapped in this study, north of Chinitna Bay. However, the trace of the Bruin Bay fault cannot be correlated in a simple linear fashion between the two regions. Figure 8-6 presents five alternative models to account for the structural linkages across Chinitna Bay. This segment of the Bruin Bay fault may exhibit either a right-stepping bend (fig. 8-6A; see also Detterman and Hartsock, 1966), or a right-stepping stepover (fig. 8-6B) associated with sinistral

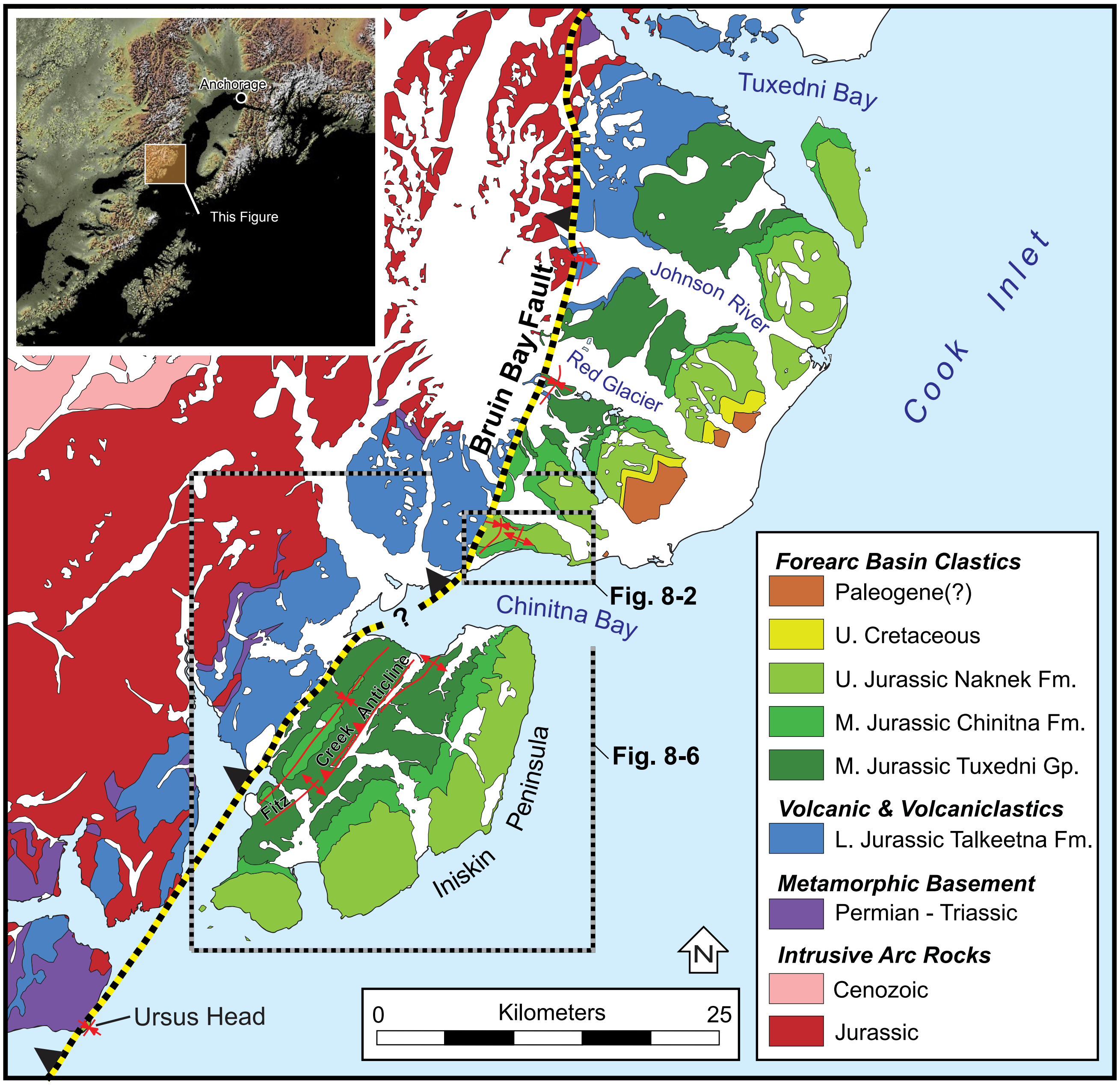

Figure 8-1. Simplified geologic map of western Cook Inlet, modified from compilation by Wilson and others (2012).

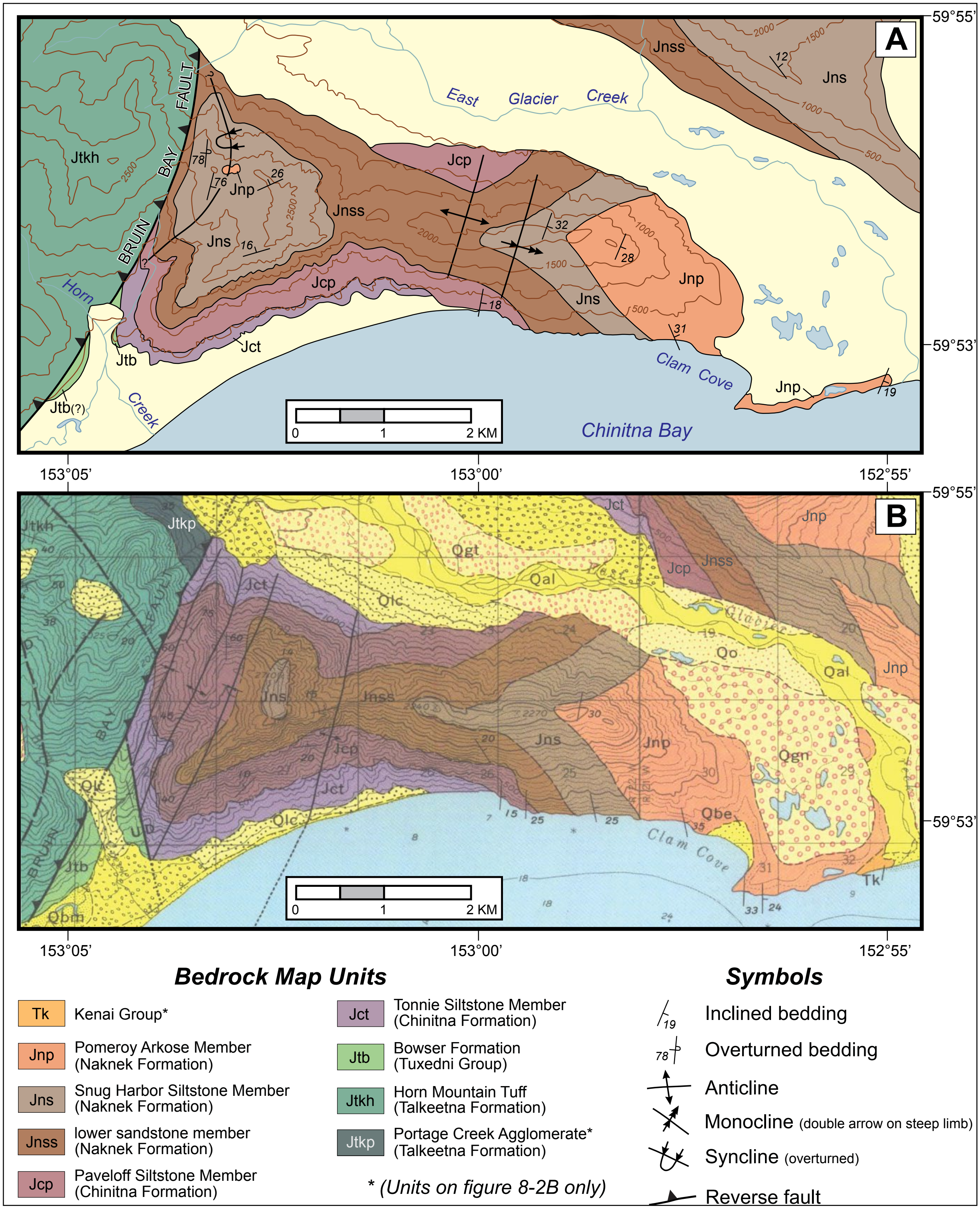

Figure 8-2. Geologic maps of the upland region between Chinitna Bay and East Glacier Creek. ***A.*** *Simplified version of new mapping completed in this study;* ***B.*** *snippet of equivalent map area from Detterman and Hartsock (1966). See figure 8-1 for map location and Detterman and Hartsock (1966) for explanation of Quaternary units and other symbols and line styles not utilized in figure 8-2A.*

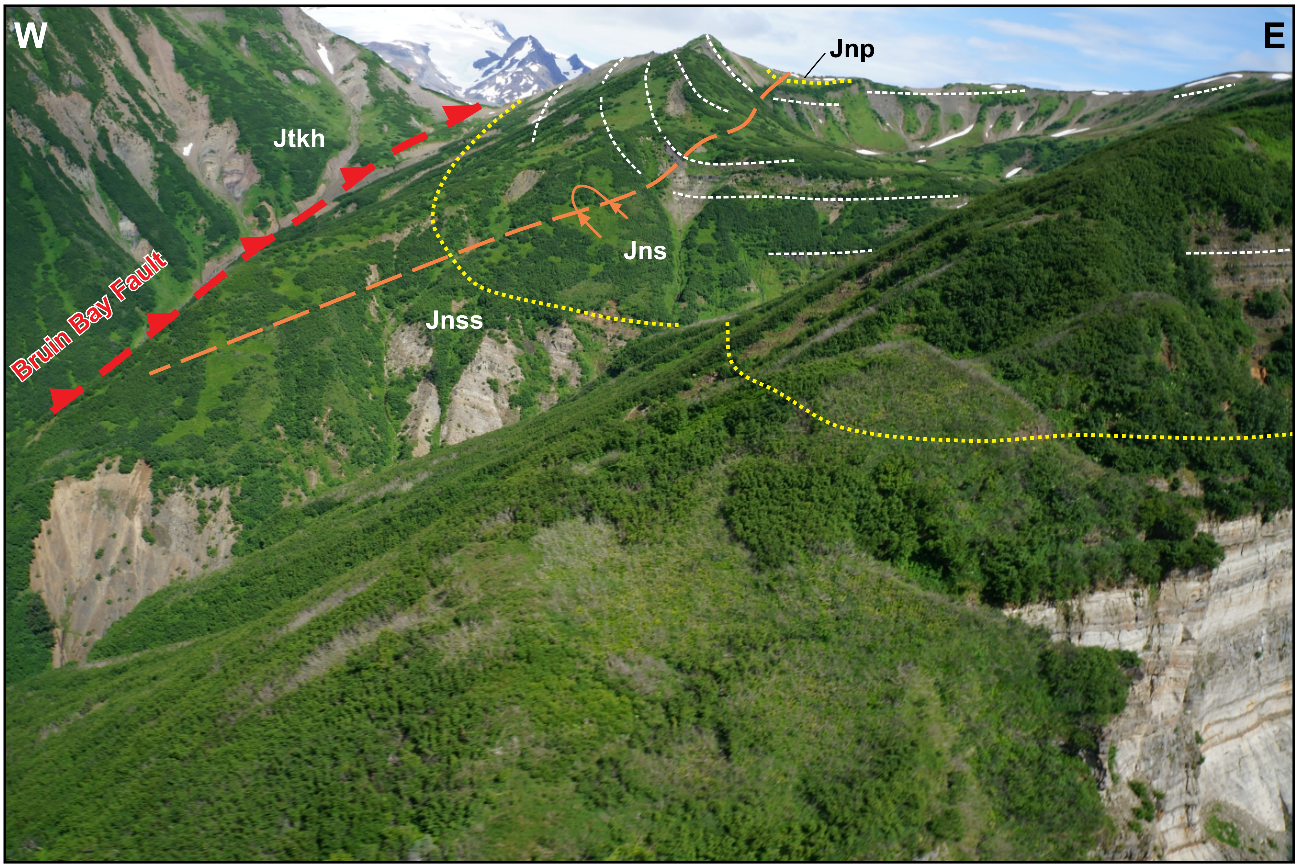

Figure 8-3. Aerial view to the north illustrating the mapped syncline in the footwall of the Bruin Bay fault. Key to line colors: Mapped fold axis shown in orange, map unit contacts in yellow, and selected bed traces in white to highlight the structure. See figure 8-2 for explanation of map unit abbreviations.

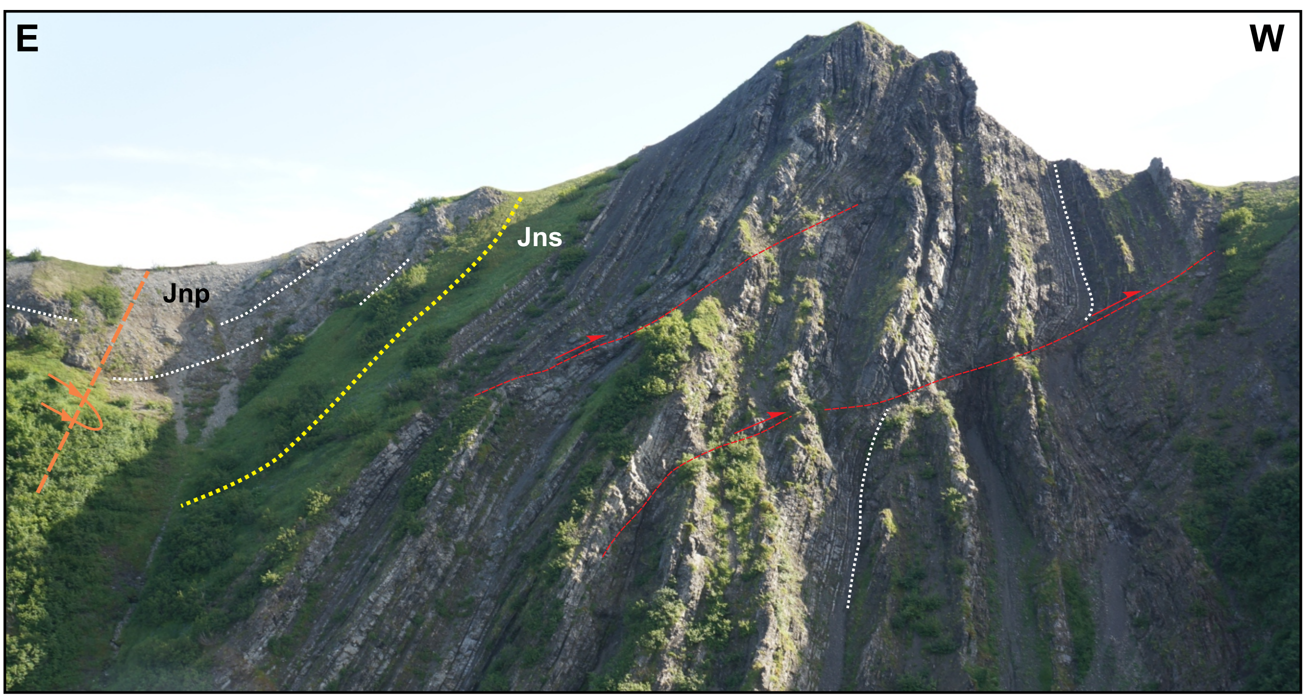

Figure 8-4. View to the south showing out-of-syncline thrust faults (dashed red lines) accommodating the "space problem" near the core of the tight fold. Key to line colors: Mapped fold axis shown in orange, map unit contacts in yellow, and selected bed traces in white to highlight the structure. See figure 8-2 for explanation of map unit abbreviations.

Figure 8-5. View to the south depicting a pseudo-cross-sectional view of the mapped area of figure 8-2. Key to line colors: Mapped fold axis shown in orange, map unit contacts in yellow, and selected bed traces in white to highlight the structure. See figure 8-2 for explanation of map unit abbreviations.

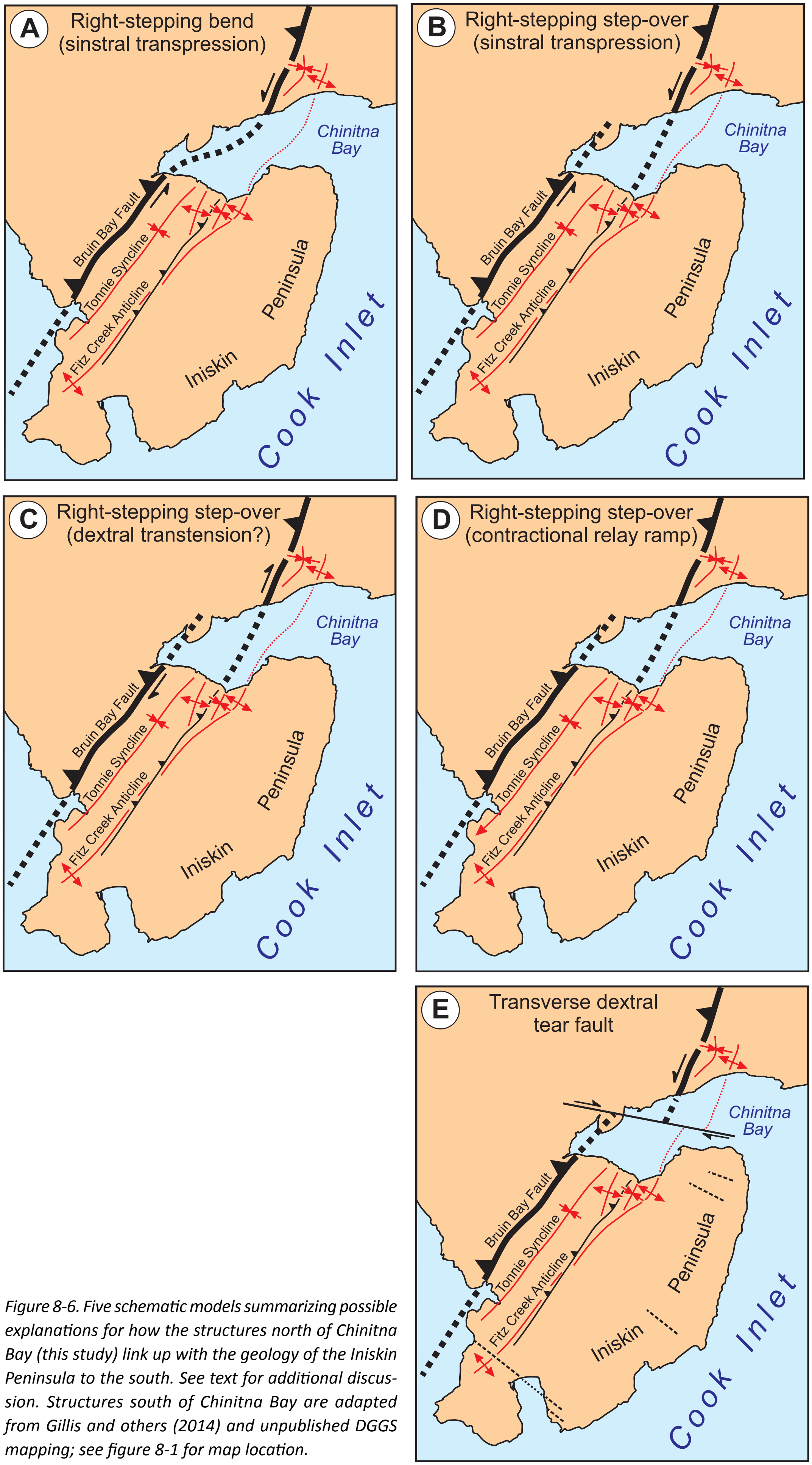

Figure 8-6. Five schematic models summarizing possible explanations for how the structures north of Chinitna Bay (this study) link up with the geology of the Iniskin Peninsula to the south. See text for additional discussion. Structures south of Chinitna Bay are adapted from Gillis and others (2014) and unpublished DGGS mapping; see figure 8-1 for map location.

transpressional motion. These two scenarios predict the development of an en echelon array of contractional structures oblique to the strands—a pattern that is not readily apparent in available mapping. Alternatively, a right-stepping bend or stepover could have developed during overall dextral transpression (fig. 8-6C), although the strike-slip component in this geometry would favor extension between the strands, which is not observed. Figure 8-6D illustrates a scenario where the fault is dominantly dip-slip (contractional), with a relay ramp between overlapping strands (see also Hartsock, 1954). This type of transfer zone may be consistent with the southwest plunge of the footwall Tonnie syncline. A final speculative model involves a transverse dextral tear fault offsetting the Bruin Bay fault and projecting beneath Chinitna Bay (fig. 8-6E). Although no direct evidence for such a fault has been observed, several fracture swarms and small-displacement faults of a similar orientation occur on the Iniskin Peninsula, some of which are associated with oil and gas seeps (Detterman and Hartsock, 1966).

ACKNOWLEDGMENTS

Fieldwork associated with DGGS's Cook Inlet program is primarily funded by a State of Alaska Capital Improvement Project. Mapping efforts in 2013 and 2015 were partially supported by funding from the U.S. Geological Survey's National Cooperative Geologic Mapping Program (STATEMAP award numbers G13AC00157 and G15AC00199). This work would not have been possible without the permitting assistance of Buck Mangipane and Jeff Shearer at Lake Clark National Park and Preserve.

Helicopter pilot Merlin "Spanky" Handley is thanked for providing safe field transportation, often in difficult weather. We thank the owners and staff of the Snug Harbor Wilderness Lodge on Chisik Island for their hospitality. Trystan Herriott provided helpful discussions of the map relations and Paul Betka contributed insight into structures associated with the Bruin Bay fault. Trystan Herriott and David LePain provided useful review comments that improved the manuscript.

REFERENCES CITED

Betka, P.M., and Gillis, R.J., 2016 (this volume), Observations on the Bruin Bay fault system between Chinitna and Tuxedni bays, Cook Inlet, Alaska, *in* Herriott, T.M., ed., Petroleum-related geologic studies in Lower Cook Inlet during 2015, Iniskin–Tuxedni region, south-central Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2016-1, p. 73–78. doi:10.14509/29544

Betka, P.M., and Gillis, R.J., 2015, Superposition of strike-slip and reverse-slip faults in the Bruin Bay fault system, Ursus Head, lower Cook Inlet, *in* Wartes, M.A., ed., Energy-related studies during the 2014 field season, western Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2015-5-2, p. 5–8. doi:10.14509/29457

Betka, P.M., and Gillis, R.J., 2014, Preliminary characterization of brittle deformation on the Iniskin Peninsula—Implications for the kinematic history of the Bruin Bay fault system, lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2014-5, 14 p. doi:10.14509/29130

Detterman, R.L., and Hartsock, J.K., 1966, Geology of the Iniskin–Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p., 6 sheets, scale 1:63,360.

Detterman, R.L., and Reed, B.L., 1980, Stratigraphy, structure, and economic geology of the Iliamna Quadrangle, Alaska: U.S. Geological Survey Bulletin 1368-B, p. B1–B86, 1 sheet, scale 1:250,000.

Gillis, R.J., ed., 2013, Overview of 2012 field studies—Upper Alaska Peninsula and west side of lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2013-1, 48 p. doi:10.14509/24824

Gillis, R.J., ed., 2014, Cook Inlet program 2013 field studies—Observations and preliminary interpretations from new 1:63,360-scale geologic mapping of the Iniskin Peninsula, lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2014-2, 31 p. doi:10.14509/27303

Gillis, R.J., Swenson, R.F., Wartes, M.A., and Frohman, R.A., 2013, Reconnaissance investigations of the Bruin Bay fault system along the western margin of lower Cook Inlet and upper Alaska Peninsula, *in* Gillis, R.J., ed., Overview of 2012 field studies—Upper Alaska Peninsula and west side of lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2013-1G, p. 33–37. doi:10.14509/24850

Gillis, R.J., Wartes, M.A., Herriott, T.M., Bull, K.F., Decker, P.L., and Betka, P.M., 2014, Overview of new 1:63,360-scale geologic mapping of the Iniskin Peninsula, lower Cook Inlet, Alaska, *in* Gillis, R.J., ed., Cook Inlet program 2013 field studies—Observations and preliminary interpretations from new 1:63,360-scale geologic mapping of the Iniskin Peninsula, lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2014-2-1, p. 3–6. doi:10.14509/27306

Hartsock, J.K., 1954, Geologic map and structure sections of the Iniskin Peninsula and adjacent area of Alaska: U.S. Geological Survey Open-File Report 54-118, 1 p., 3 sheets.

Herriott, T.M., ed., 2016 (this volume), Petroleum-related geologic studies in Lower Cook Inlet during 2015, Iniskin–Tuxedni region, south-central Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2016-1, 78 p. doi:10.14509/29532

Herriott, T.M., and Wartes, M.A., 2014, Geologic-mapping-based observations of the Middle Jurassic Chinitna Formation and Upper Jurassic Naknek Formation in the Tilted Hills, Iniskin Peninsula, Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2014-3, 23 p. doi:10.14509/27305

LePain, D.L., Stanley, R.G., Helmold, K.P., and Shellenbaum, D.P., 2013, Geologic framework and petroleum systems of Cook Inlet basin, south-central Alaska, *in* Hite, D.M., and Stone, D.M., eds., Oil and gas fields of the Cook Inlet Basin, Alaska: American Association of Petroleum Geologists Memoir 104, p. 37–116.

Mitra, Shankar, 2002, Fold-accommodation faults: American Association of Petroleum Geologists Bulletin, v. 86, no. 4, p. 671–693. doi:10.1306/61EEDB7A-173E-11D7-8645000102C1865D

Stanley, R.G., Pierce, B.S., and Houseknecht, D.W., 2011, U.S. Geological Survey 2011 assessment of undiscovered oil and gas resources of the Cook Inlet region, south-central Alaska: U.S. Geological Survey Open-File Report 2011-1137, 37 p.

Wartes, M.A., ed., 2015, Energy-related studies during the 2014 field season, western Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2015-5, 62 p. doi:10.14509/29455

Wartes, M.A., Decker, P.L., Herriott, T.M., and Helmold, K.P., 2015, Preliminary facies analysis of the lower sandstone member of the Upper Jurassic Naknek Formation, northern Chinitna Bay, Alaska, *in* Wartes, M.A., ed., Energy-related studies during the 2014 field season, western Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2015-5-8, p. 49–55. doi:10.14509/29463

Wartes, M.A., Herriott, T.M., Helmold, K.P., and Gillis, R.J., 2013, Preliminary stratigraphic interpretation of the Naknek Formation—Evidence for Late Jurassic activity on the Bruin Bay fault, Iniskin Peninsula, lower Cook Inlet, *in* Gillis, R.J., ed., Overview of 2012 field studies—Upper Alaska Peninsula and west side of lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Preliminary Interpretive Report 2013-1H, p. 39–46. doi:10.14509/24851

Wilson, F.H., Hults, C.P., Schmoll, H.R., Haeussler, P.J., Schmidt, J.M., Yehle, L.A., and Labay, K.A., compilers, 2012, Geologic map of the Cook Inlet region, Alaska, including parts of the Talkeetna, Talkeetna Mountains, Tyonek, Anchorage, Lake Clark, Kenai, Seward, Iliamna, Seldovia, Mount Katmai, and Afognak: U.S. Geological Survey Scientific Investigations Map 3153, 76 p., 2 sheets, scale 1:250,000.