STRATIGRAPHY AND SEDIMENTOLOGY OF THE CHINITNA FORMATION, INISKIN–TUXEDNI BAYS AREA, SOUTH-CENTRAL ALASKA—LATE MIDDLE JURASSIC DEPOSITIONAL SYSTEMS AND PETROLEUM PROSPECTIVITY IN COOK INLET FOREARC BASIN

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CONTEXT, HIGHLIGHTS, AND RESULTS

Oil production in Cook Inlet forearc basin is from Tertiary reservoirs

Oil source rocks in the basin occur in the Middle Jurassic Tuxedni Group and/or Triassic stratigraphy

Does the Middle Jurassic Chinitna Formation have oil reservoir potential?

① • Chinitna Formation comprises ~700 m of dominantly fine-grained marine forearc basin strata

② • Sedimentologic work suggests primarily shallow-marine deposition, but there are indications that some Chinitna strata may record deep-water (for example, slope) sedimentation

③
- Mountain-scale exposures reveal stratigraphic cycles in the Chinitna Formation
  - Coarse-grained basal successions in each member are lowstand systems tracts
    - Coarse detritus was exported beyond the outcrop belt during these lowstands
  - Finer-grained middle and upper parts of each member are transgressive and highstand systems tracts, although stratigraphic relations within mid-Paveloff may reflect an additional base-level cycle

④ • Paveloff sandstones are feldspathic and generally have <6% porosity and <0.2 millidarcies permeability

⑤ • Oil-stained basal Paveloff (Jcp_1) crops out at Chinitna Bay

The depositional-systems and sequence-stratigraphic framework of this study—and an oil-stained outcrop—demonstrate that viable scenarios exist for oil reservoirs in the Chinitna Formation

Chinitna Formation stratigraphic cyclicity reflects at least two episodes when coarse detritus was exported into the basin and should be recognized in the context of Mesozoic play concepts for Cook Inlet

ABSTRACT

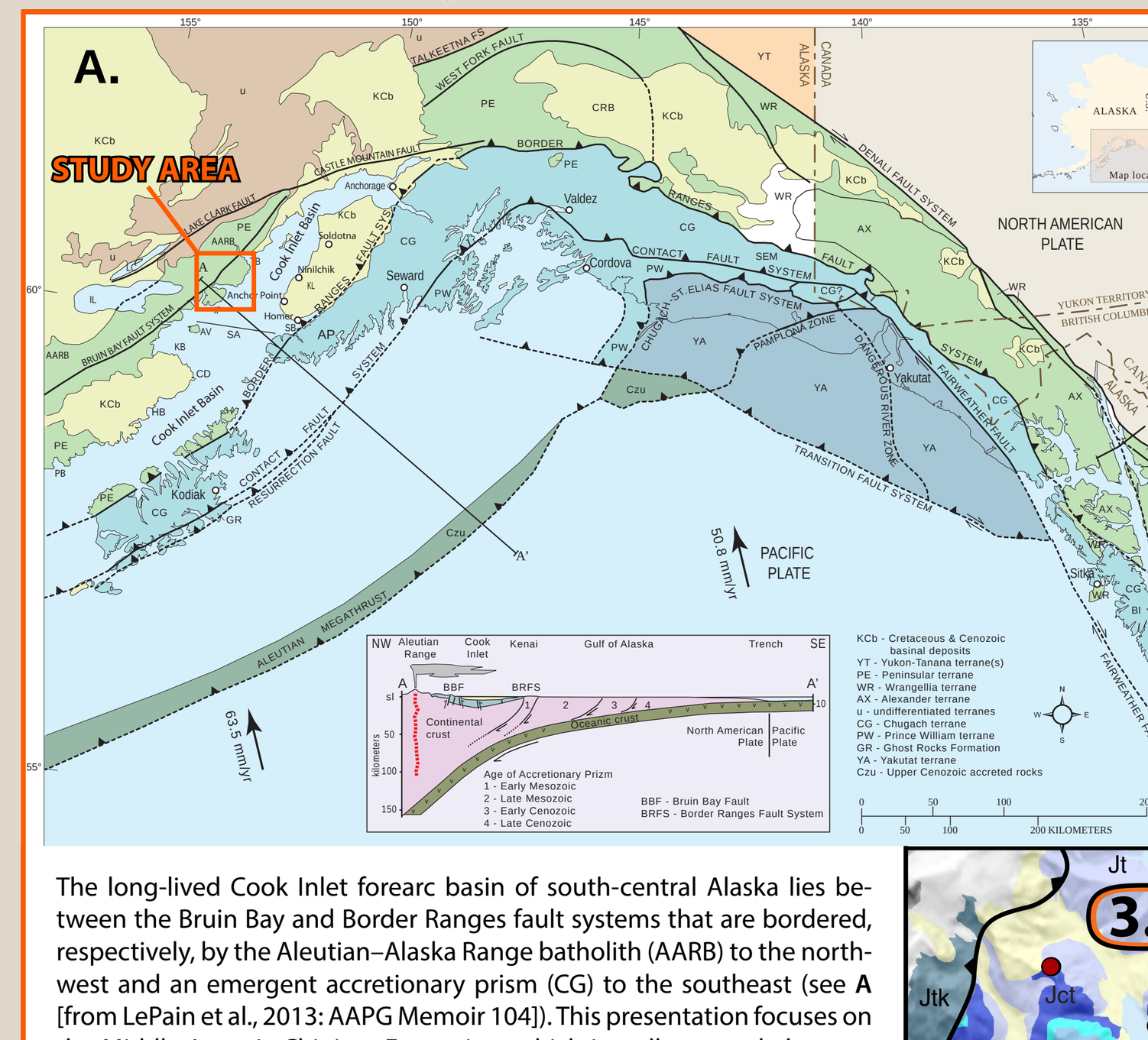
The Chinitna Formation of lower Cook Inlet is a ~700-m-thick marine unit that crops out near the arc-proximal forearc basin margin. Two members of comparable thickness are mapped as Tonnie Siltstone (Bathonian–Callovian) and Paveloff Siltstone (Callovian). Geologic mapping, stratigraphic reconnaissance, and sedimentologic work provide new insights into the Chinitna.

A ~70-m-thick channelized conglomerate package at Chisik Island is reportedly associated with Tonnie, but field relations indicate these beds may be younger than Tonnie. Nevertheless, lower Tonnie exposures near Tonnie Peak do host channelized, cross-stratified sandstone. At Iniskin Bay, part of lower Tonnie exhibits thin, sharp-based sandstone intercalated with bioturbated siltstone; hummocky cross-stratified sandstone is also present. Reconnaissance of upper Tonnie reveals a finer-grained interval with local gully-scale channel-forms and mainly fine-grained fills. A generally comparable stratigraphic stacking motif is documented in Paveloff. A ~100-m-thick succession of tabular and channelized sandstone and conglomerate commonly occurs at this member's base, and hummocky cross stratification is also noted. Regionally, overlying finer-grained deposits are observed. Upper Paveloff at Chinitna Bay comprises more than 160 m of bioturbated, very fine-grained sandstone with subordinate coarser, sharp-based sandstone; slump scars and channels with m-scale relief are principally filled with fine-grained detritus. Mountain-scale exposures exhibit even larger channel-forms in upper Paveloff, including a slump-associated feature with ~140 m of stratigraphic relief.

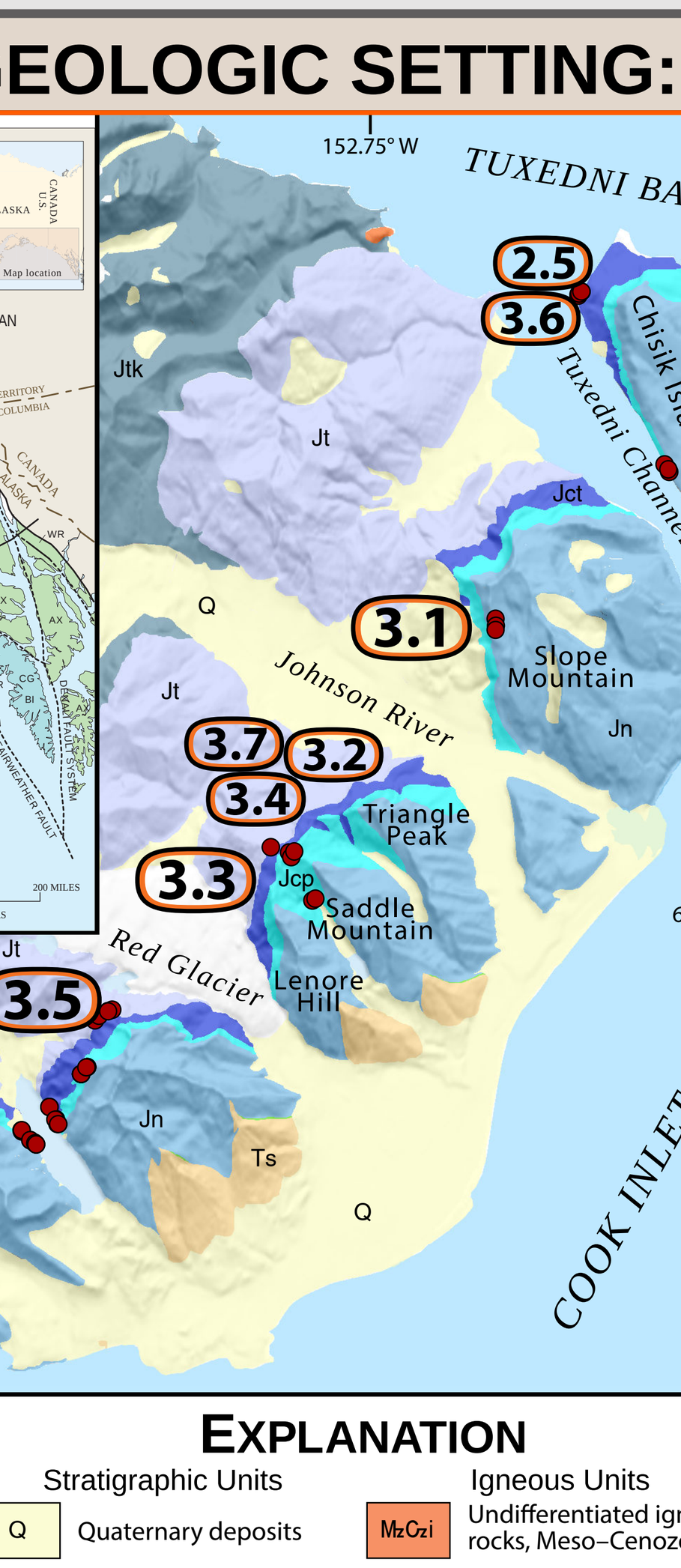
Tonnie and Paveloff each record third-order sedimentation cycles. Regressive, lowstand depositional systems with probable delta associations supplied coarse sediment during onset of each cycle. The conglomerate at Chisik Island highlights marked base-level fall (10s of m of incision), probably represents shelf-valley fill, and is tentatively associated with Paveloff rather than Tonnie. Overlying finer-grained successions in both members may reflect waning deltaic influences as near-shore environments were transgressed during rising base level, diminishing sediment supply to prodelta settings in shelfal water depths ranging down to—and perhaps below—storm wave base. Continued transgressions likely terminated direct deltaic inputs into outer shelf settings. The lithologically monotonous, gullied upper parts of each member may record highstand normal regressions—rather than continued transgressions—when muddy clinoforms(?) of delta- to slope-scale relief prograded into the basin during later periods of base-level rise; the strongest evidence for this scenario occurs in Paveloff, where the largest channel-form approaches submarine-canyon-scale.

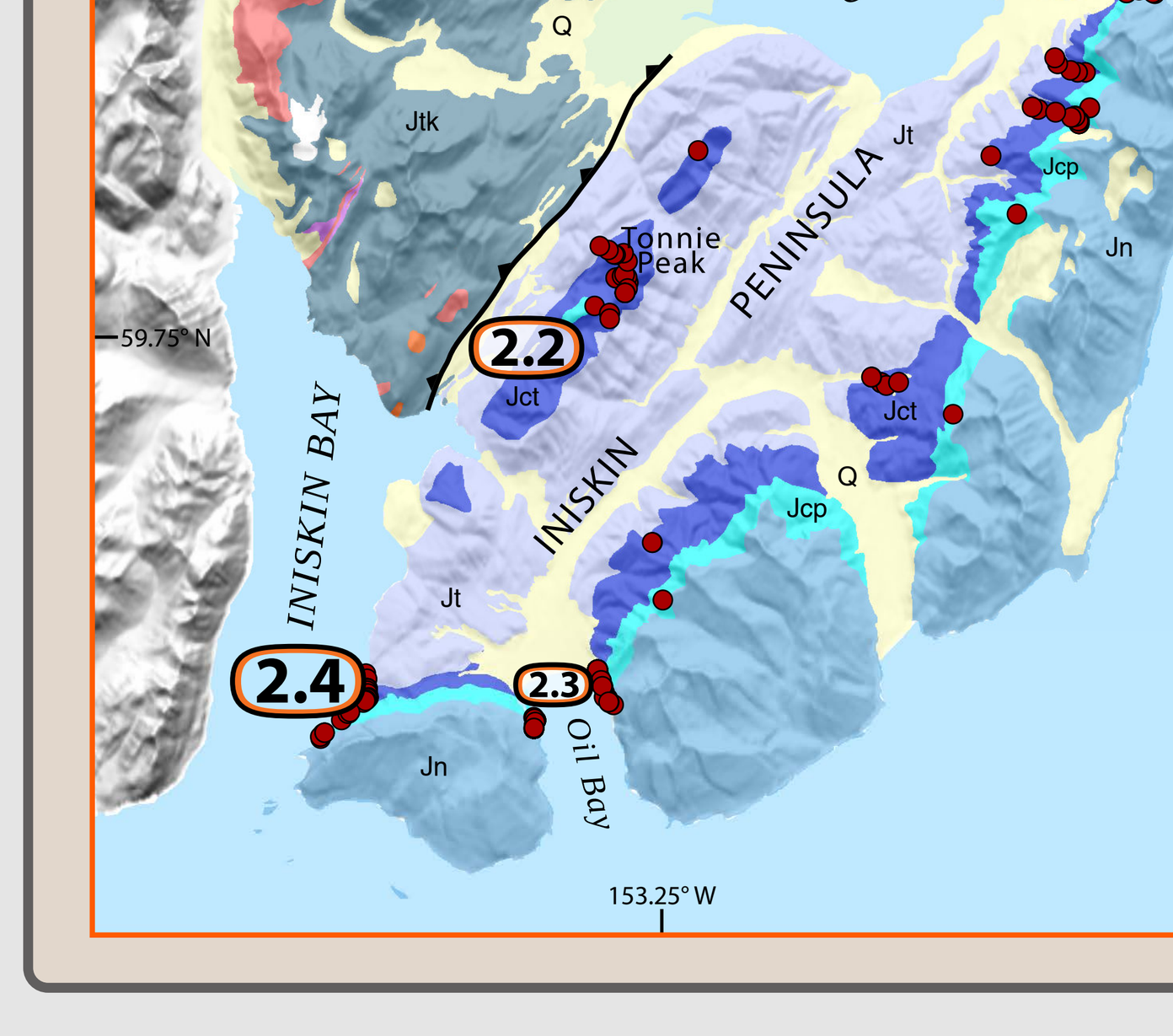
Rock-Eval pyrolysis results from 44 samples (12 from Tonnie, 32 from Paveloff) indicate poor petroleum source potential, with total organic carbon values of 0.14–0.69 weight percent and S2 values of 0.00–0.57 milligrams hydrocarbon per gram of rock. Thermal maturity of the samples ranges from ~0.7% Ro at Oil Bay to 0.85–1.20% Ro at Iniskin Bay based on Rock-Eval Tmax, spore color, and vitrinite reflectance analyses. Sampled Chinitna sandstones are mainly feldspathic and generally have less than 6% porosity and less than 0.2 millidarcies permeability. Nevertheless, migrated oil is documented in a lower Paveloff outcrop, and viable scenarios exist for Chinitna-hosted oil accumulations.

① LOCATION AND GEOLOGIC SETTING: INISKIN–TUXEDNI BAYS AREA



The long-lived Cook Inlet forearc basin of south-central Alaska lies between the Bruin Bay and Border Ranges fault systems that are bordered, respectively, by the Aleutian–Alaska Range batholith (AARB) to the northwest and an emergent accretionary prism (CG) to the southeast (see **A** [from LePain et al., 2013: AAPG Memoir 104]). This presentation focuses on the Middle Jurassic Chinitna Formation, which is well exposed along an outcrop trend between Iniskin and Tuxedni bays of lower Cook Inlet. We made observations of the Chinitna Formation at ~350 localities since our work in lower Cook Inlet began in 2009. Geologic mapping (**B**) southwest of Johnson River is preliminary and simplified (DGGS, unpublished data); farther northeast, mapping is after Detterman and Hartsock (1966: USGS Professional Paper 512), and is an area where DGGS and collaborators will map the geology during summer 2017.





EXPLANATION

Stratigraphic Units
- Q — Quaternary deposits
- Ts — Tertiary strata
- Ks — Upper Cretaceous strata
- Jn — Naknek Formation, Upper Jurassic
- Jcp — **Paveloff Siltstone Member**
- Jct — **Tonnie Siltstone Member**
- Jt — Tuxedni Group, Middle Jurassic
- Jtk — Talkeetna Formation, Lower Jurassic
- Trm — Marble, Triassic(?)

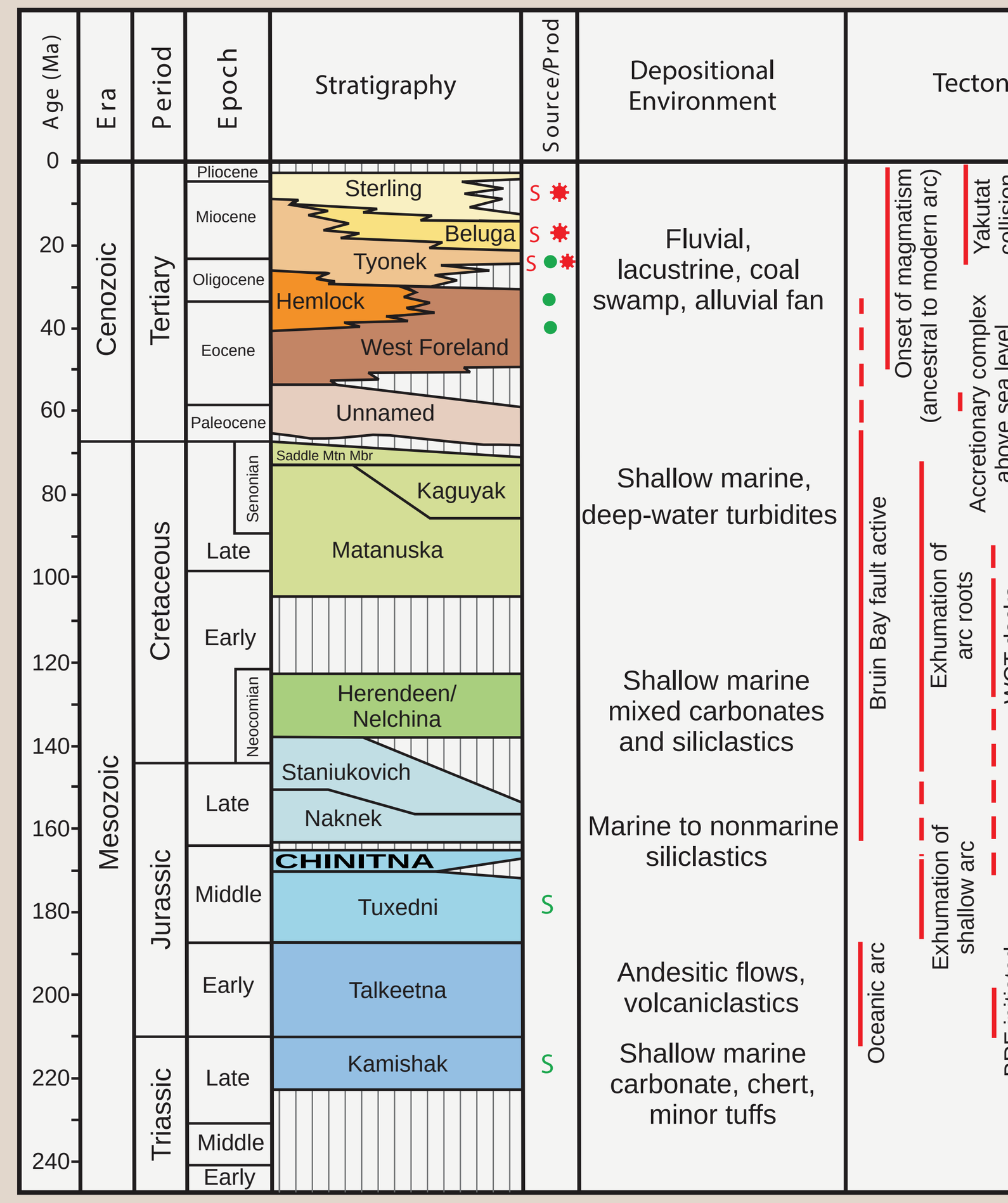
Igneous Units
- MzCzi — Undifferentiated igneous rocks, Meso–Cenozoic
- Jp — Plutonic rocks, Jurassic

CHINITNA FORMATION (Middle Jurassic)—Marine siltstone and sandstone, with subordinate conglomerate. Each member hosts a coarse-grained basal succession with probable delta associations. Regional layer-cake-like stacking, but complex stratigraphic architecture is expressed in mountain-scale exposures. Typically ~700 m thick, with each member of comparable thickness. See Herriott and Wartes (2014: doi: 10.14509/27305) and references therein for further description.

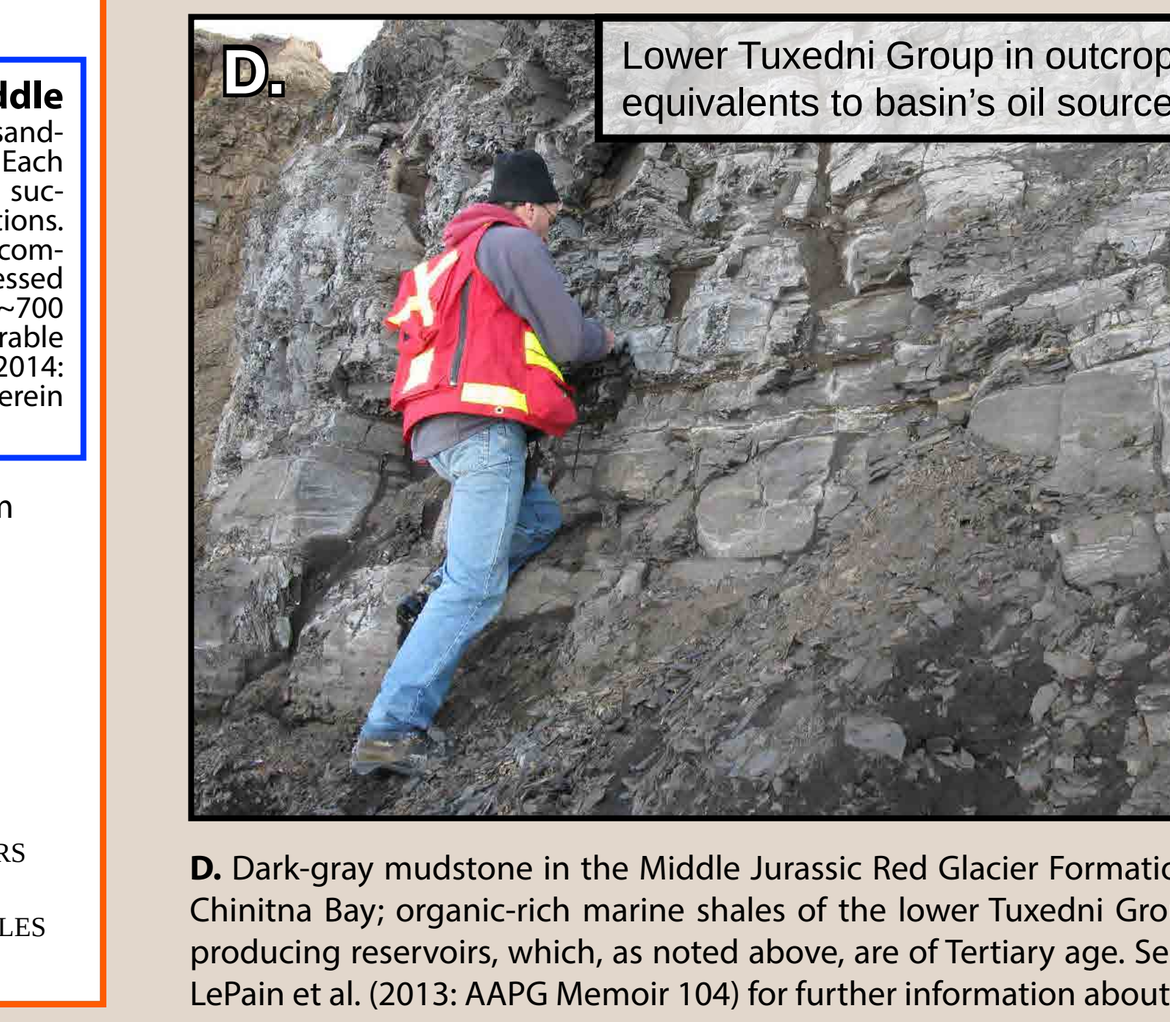
- Bruin Bay fault system
- Chinitna Formation observation locality
- Locality discussed on poster

SCALE APPROXIMATELY 1:125,000

COOK INLET STRATIGRAPHY



C. The siliciclastic record in Cook Inlet basin comprises more than 35,000 feet of Middle Jurassic through Cretaceous marine strata and up to 25,000 feet of nonmarine Tertiary stratigraphy. Oil and gas are produced from sandstones within the Tertiary section; however, the oil is sourced from the underlying Middle Jurassic Tuxedni Group (see also **D**) and/or the Triassic Kamishak Formation, whereas the gas—of biogenic origin—is sourced from Tertiary coals. Red S indicates gas source rock; green S indicates oil source rock; red asterisk represents gas production; green circle represents oil production. Figure modified after Gillis (2013: doi: 10.14509/24824 [p. 1–4]) and references therein.

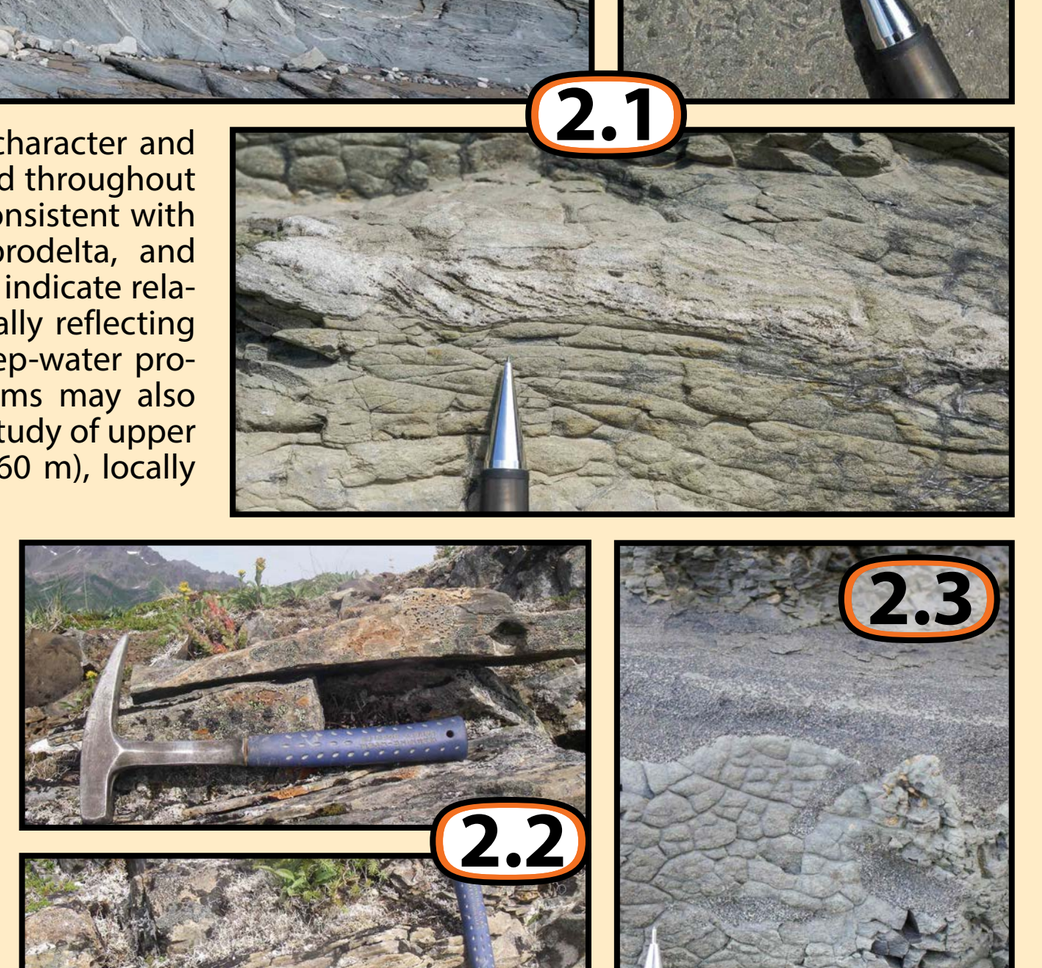


D. Dark-gray mudstone in the Middle Jurassic Red Glacier Formation (Tuxedni Group) crops out near Red Glacier north of Chinitna Bay; organic-rich marine shales of the lower Tuxedni Group are likely the principal sources of oil in Cook Inlet's producing reservoirs, which, as noted above, are of Tertiary age. See Stanley et al. (2013: doi: 10.14509/24824 [p. 5–9]) and LePain et al. (2013: AAPG Memoir 104) for further information about the Red Glacier Formation. Photograph by R.G. Stanley.

② SEDIMENTOLOGY

PAVELOFF SILTSTONE MEMBER

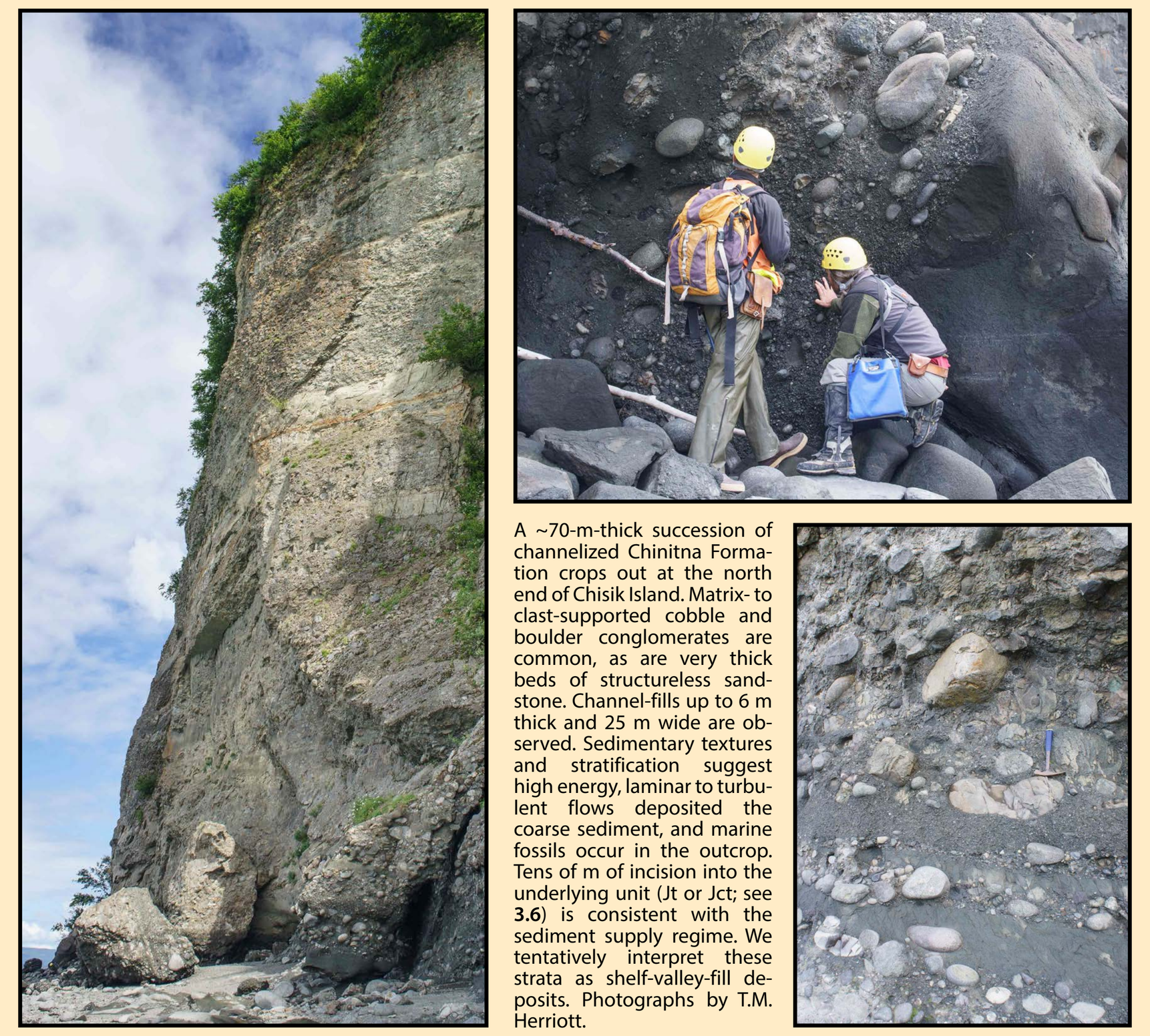
Sedimentary textures, structures, bedding character and geometries, and fossil assemblages observed throughout Paveloff Siltstone Member are principally consistent with shallow-marine sedimentation in delta, prodelta, and outer-shelf settings. Some exposures clearly indicate relatively steep depositional gradients, potentially reflecting delta-scale clinoform foresets; however, deep-water processes associated with slope-scale clinoforms may also occur in the Paveloff (see **3.7**). **2.1** Detailed study of upper Paveloff at Chinitna Bay reveals a thick (~160 m), locally slumped (above left) succession of chiefly lithologically monotonous, thoroughly bioturbated, very-fine-grained sandstone and siltstone with locally discrete *Phycosiphon* trace fossils (above right); subordinate thin beds of fine-grained sandstone are commonly ripple laminated (right). Photographs by M.A. Wartes. **2.2** Excellent exposures of lower Paveloff occur in the Tonnie Peak area, where probable hummocky cross-stratified sandstones are observed. Photographs by P.L. Decker. **2.3** Detailed study of Paveloff in Oil Bay indicates a prodelta setting within the member. Thin, sharp-based sandstone beds are sediment gravity flow deposits, which are locally bioturbated (see example of *Thalassinoides* to right of pencil tip). Photograph by T.M. Herriott.



2.4 TONNIE SILTSTONE MEMBER

Similar to Paveloff, observations of sedimentary textures, structures, bedding, and fossils throughout Tonnie Siltstone Member are consistent with shallow-marine sedimentation in delta, prodelta, and outer-shelf settings. The generally thin-bedded, very-fine-grained sandstone and siltstone (above left) of the upper ~200 m of Tonnie is well exposed at Iniskin Bay (below left). Trace fossils (e.g., below right: *Planolites[?]*), body fossils (e.g., ammonite at left), and thin-bedded and sharp-based sandstones (above right) are suggestive of prodelta and/or outer-shelf(?) settings that may have been prone to storm-influenced sedimentation. Fossil and plant debris in pot-cast-like features (left) may be biogenic collections. The upper part of Tonnie at Iniskin bay (below left) hosts a gully-scale cut-and-fill element—although the stratigraphic relations are somewhat obscured by faulting—that may be associated with highstand progradation (see also **3.4** and **3.7**). Photographs by T.M. Herriott.

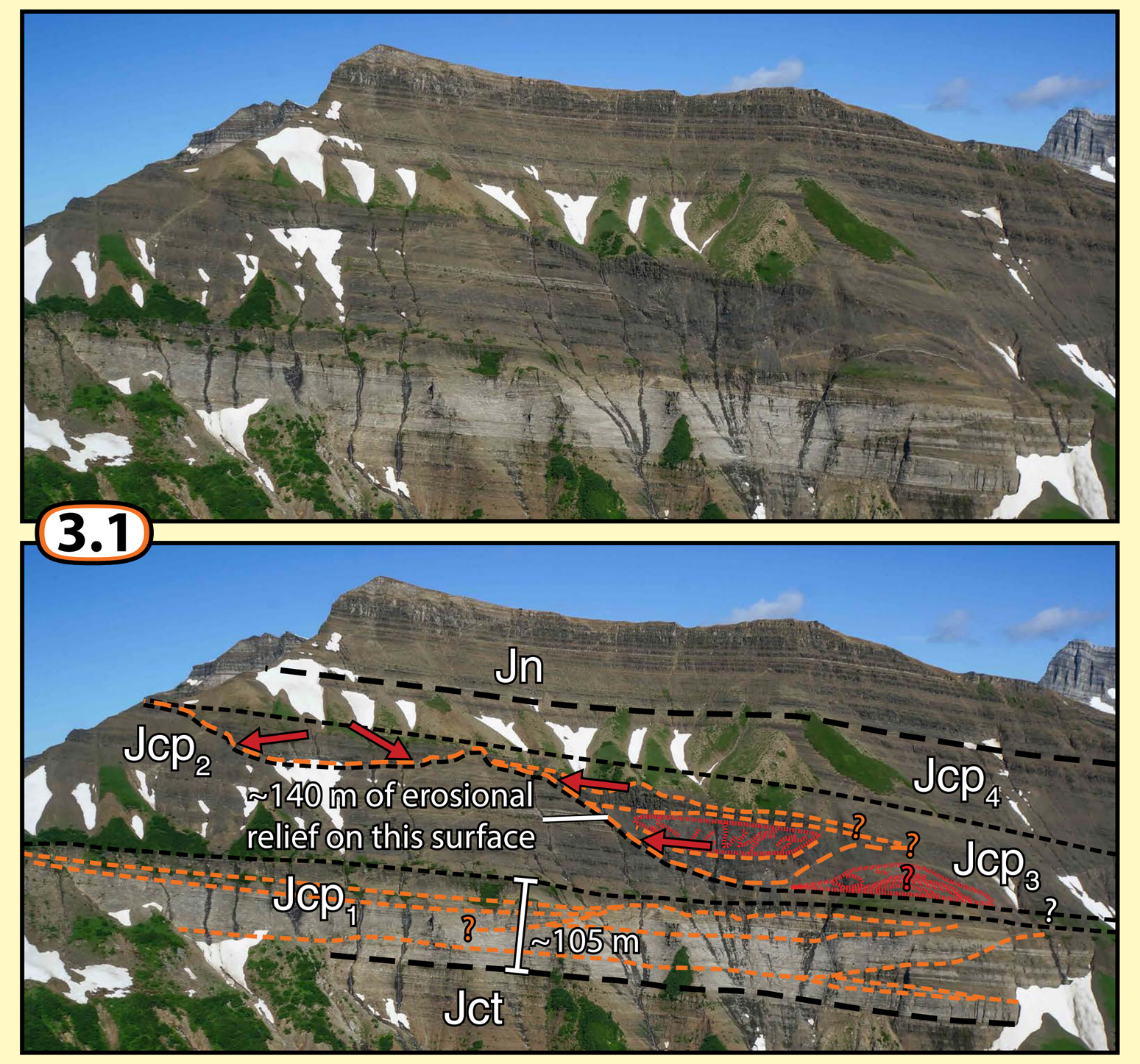
2.5 CONGLOMERATE AT CHISIK ISLAND

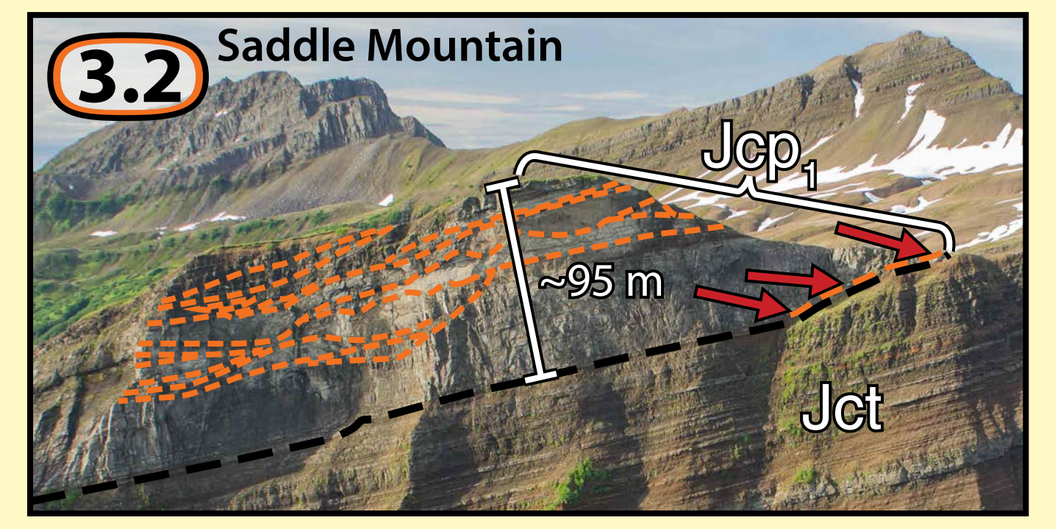


A ~70-m-thick succession of channelized Chinitna Formation crops out at the north end of Chisik Island. Matrix- to clast-supported cobble and boulder conglomerates are common, as are very thick beds of structureless sandstone. Channel-fills up to 6 m thick and 25 m wide are observed. Sedimentary textures and stratification suggest high energy, laminar to turbulent flows deposited the coarse sediment, and marine fossils occur in the outcrop. Tens of m of incision into the underlying unit (Jt or Jct; see **3.6**) is consistent with the sediment supply regime. We tentatively interpret these strata as shelf-valley-fill deposits. Photographs by T.M. Herriott.

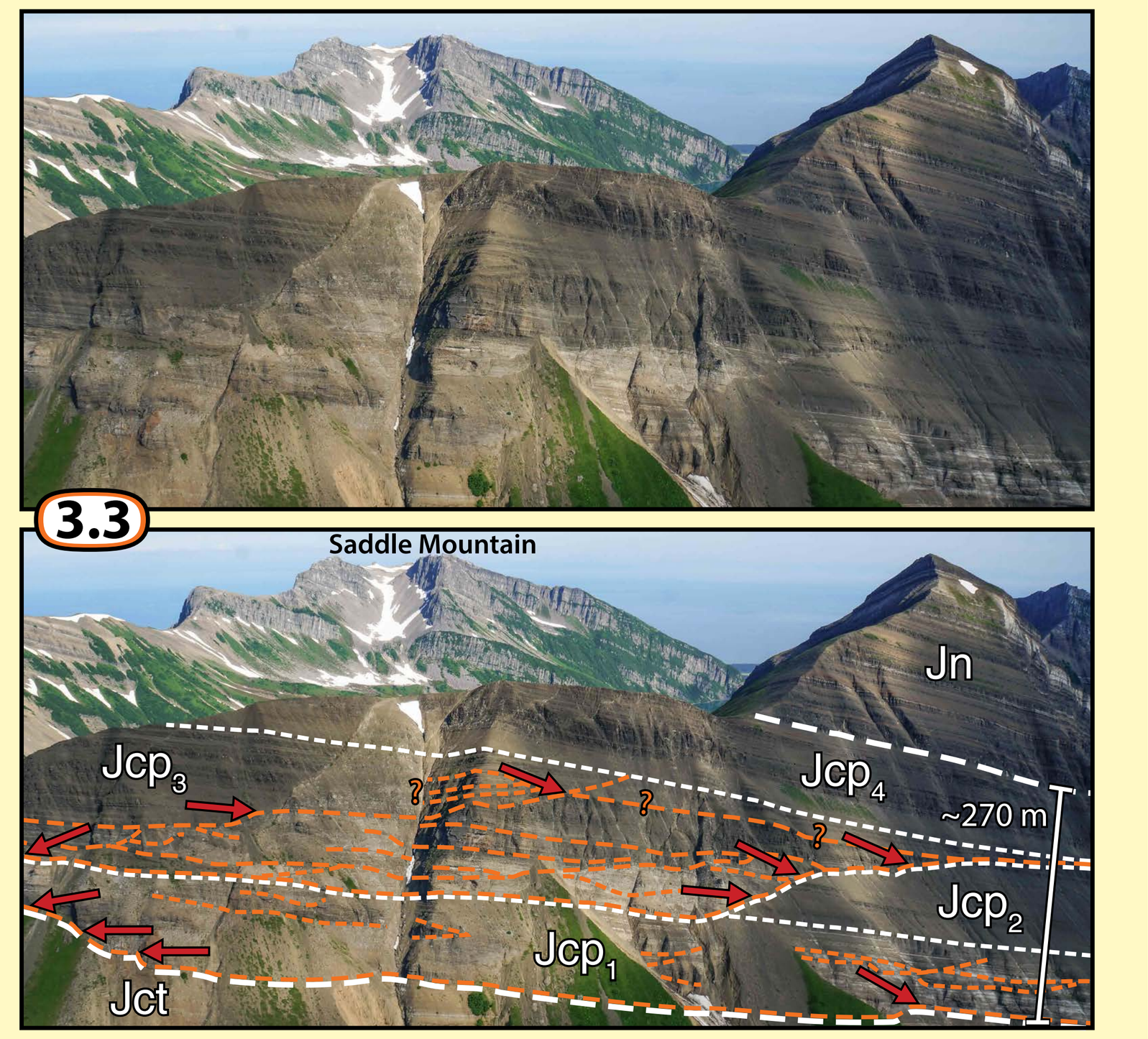
③ STRATIGRAPHIC ARCHITECTURE

PAVELOFF SILTSTONE MEMBER





3.1 Oblique aerial view eastward of Paveloff Siltstone Member northeast of Johnson River in the Slope Mountain area. A thick, channelized succession at the base of Paveloff is well developed and clearly expressed at this locality and dominantly comprises sandstone (see Jcp_1). Note high-relief erosional surface that cuts Jcp_2 and is filled by slumped, channelized, and tabular-bedded packages of Jcp_3. Photograph by M.A. Wartes.
3.2 Oblique aerial view southward of tabular-bedded (lower part) to channelized (upper part) Jcp_1 within cliff-face exposure ~1.5 km west of Triangle Peak. Channel fills are sandstone and conglomerate and commonly >10 m thick. Convolute-stratified sandstones are suggestive of rapid dewatering in a high-sedimentation-rate setting. Herriott et al. (2016: doi: 10.14509/ 29539) interpreted Jcp_1 here as likely recording deltaic processes. Photograph by T.M. Herriott.
3.3 Oblique aerial view southeastward of Paveloff in the Red Glacier area northwest of Lenore Hill. Stratigraphic architecture here is similar to the exposure at **3.1**, which lies ~12 km to the northeast. Note, however, greater relief along the Jct–Jcp contact here than is observed at **3.1**, **3.2**, or **3.7**, and the seemingly sand-rich nature (see lighter-brown-weathering strata) of lowermost Jcp_3. Two scenarios regarding the genesis of the basal Jcp_3 surface are considered below. Photograph by M.A. Wartes.
See Herriott et al. (2016: doi: 10.14509/29539) for further discussion of **3.1** and **3.2**. Subscripted architectural units are further described in **3.7**.



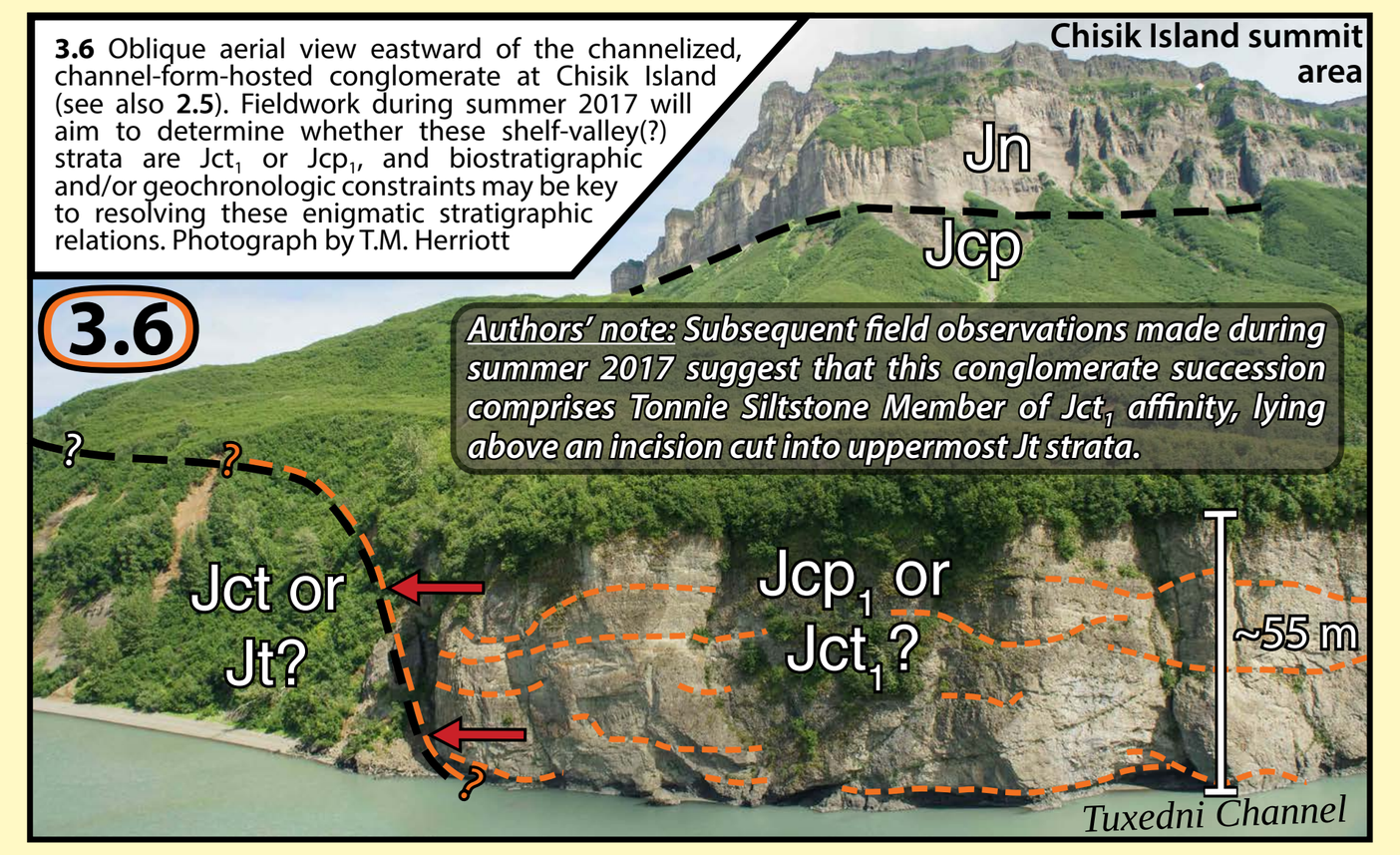
EXPLANATION

- formation/member contact
- intra-member contact
- large-scale erosional surface with onlap at arrow
- channel-form base
- deformed stratal surface/ zone of chaotic bedding
- fault—arrow indicates relative stratigraphic offset
- disrupted perspective of stratigraphy
- ~1m approximate stratigraphic thickness

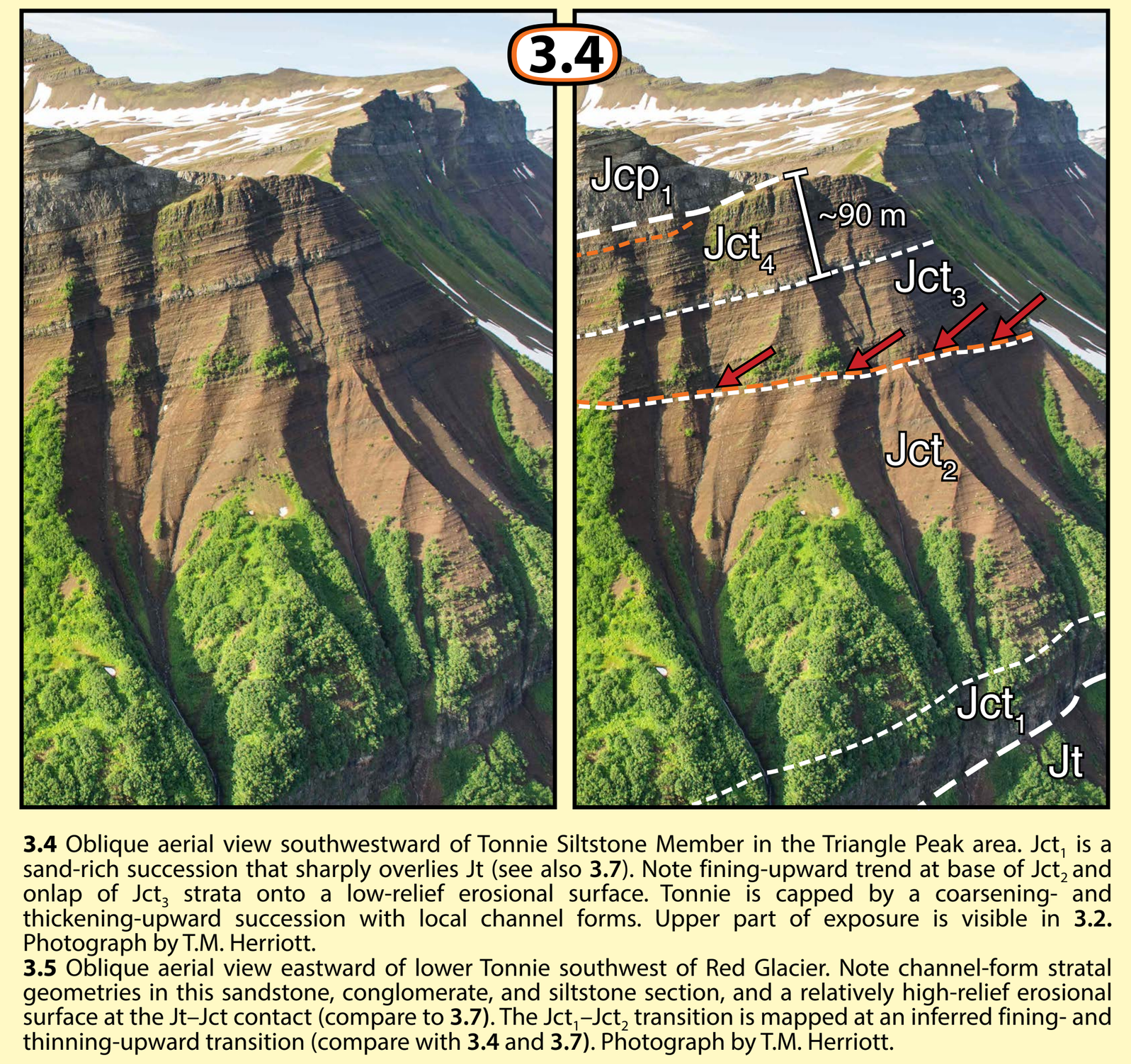
Jn—Naknek Formation
Jcp—Paveloff Siltstone Member, Chinitna Formation
Jct—Tonnie Siltstone Member, Chinitna Formation
Jt—Tuxedni Group

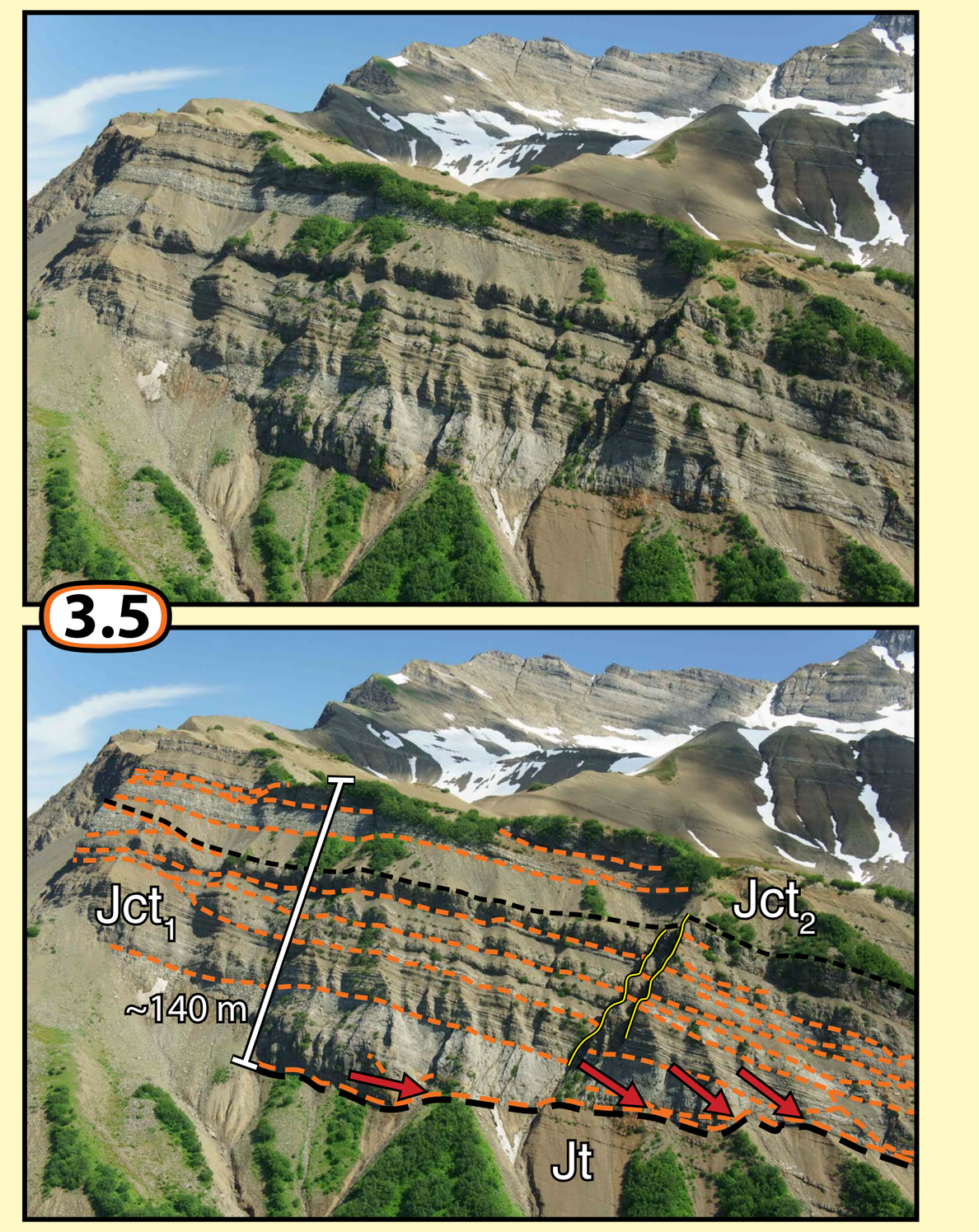
CHISIK IS.: TONNIE OR PAVELOFF?

3.6 Oblique aerial view eastward of the channelized, channel-form-hosted conglomerate at Chisik Island (see also **2.5**). Fieldwork during summer 2017 will aim to determine whether these shelf-valley(?) strata are Jct_1 or Jcp_1, and biostratigraphic and/or geochronologic constraints may be key to resolving these enigmatic stratigraphic relations. Photograph by T.M. Herriott



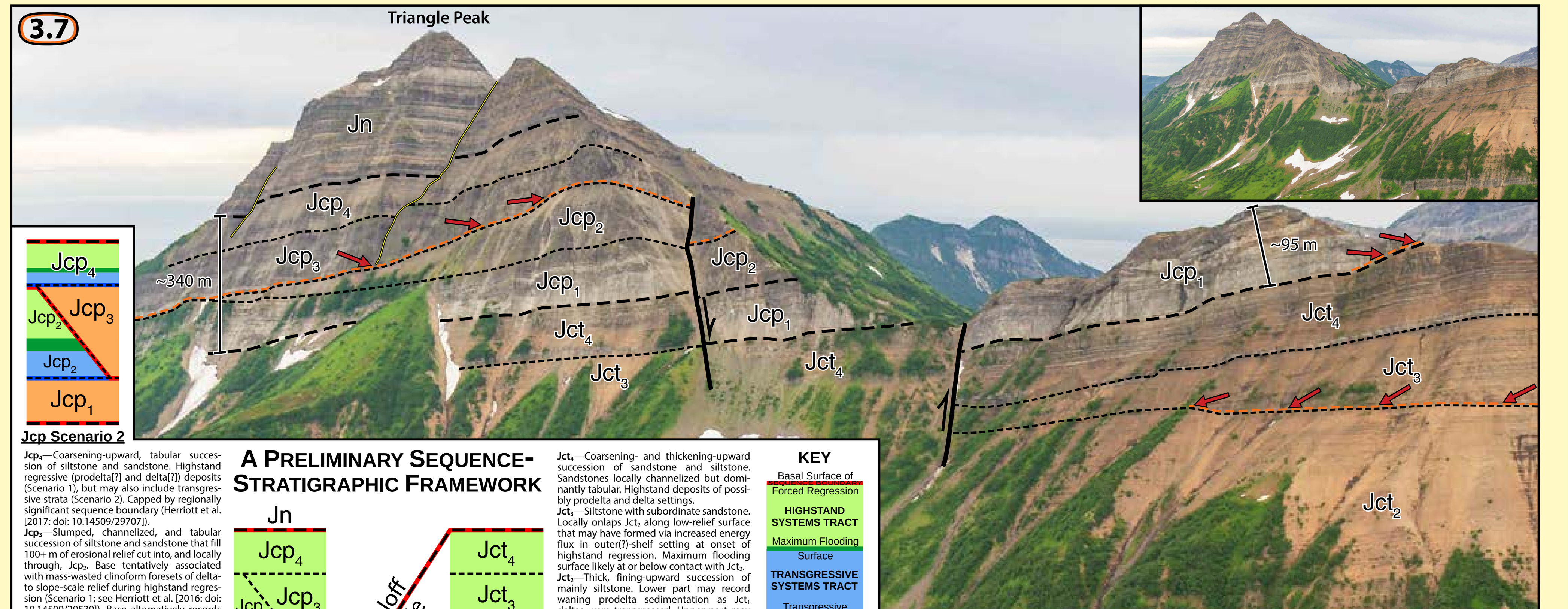
TONNIE SILTSTONE MEMBER





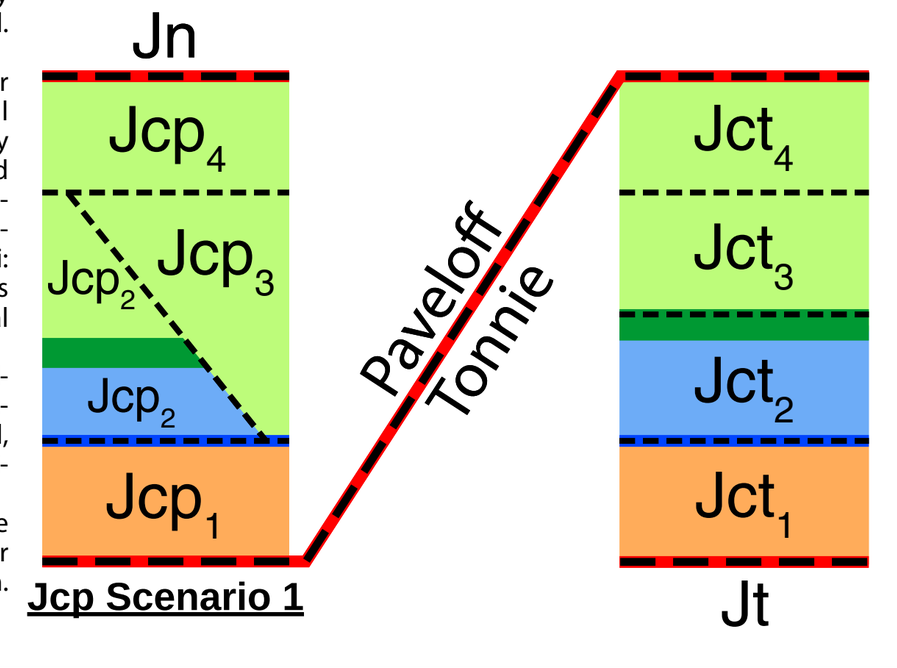
3.4 Oblique aerial view southwestward of Tonnie Siltstone Member in the Triangle Peak area. Jct_1 is a sand-rich succession that sharply overlies Jt (see also **3.7**). Note fining-upward trend at base of Jct_2 and onlap of Jct_3 strata onto a low-relief erosional surface. Tonnie is capped by a coarsening- and thickening-upward succession with local channel forms. Upper part of exposure is visible in **3.2**. Photograph by T.M. Herriott.
3.5 Oblique aerial view eastward of lower Tonnie southwest of Red Glacier. Note channel-form stratal geometries in this sandstone, conglomerate, and siltstone section, and a relatively high-relief erosional surface at the Jt–Jct contact (compare to **3.7**). The Jct_1–Jct_2 transition is mapped at an inferred fining- and thinning-upward transition (compare with **3.4** and **3.7**). Photograph by T.M. Herriott.

CHINITNA FORMATION OVERVIEW—MAP-SCALE ARCHITECTURAL UNITS AND SEQUENCE STRATIGRAPHY



Jcp₄—Coarsening-upward, tabular succession of siltstone and sandstone. Highstand regressive (prodelta[?] and delta[?]) deposits (Scenario 1), but may also include transgressive strata (Scenario 2). Capped by regionally significant sequence boundary (Herriott et al. [2017: doi: 10.14509/29707]).
Jcp₃—Slumped, channelized, and tabular succession of siltstone and sandstone that fill 100+ m of erosional relief cut into, and locally through, Jcp_2. Base tentatively associated with mass-wasted clinoform foresets of delta- to slope-scale relief during highstand regression (Scenario 1; see Herriott et al. [2016: doi: 10.14509/29539]). Base alternatively records allogenically forced base-level fall along basal surface of forced regression (Scenario 2).
Jcp₂—Thick succession of siltstone and sandstone(?). Lower part comparable to transgressive Jct_2. Upper part likely comprises shelfal, highstand regressive strata. Cryptic maximum flooding surface is intra-Jcp_2.
Jcp₁—Dominantly channelized sandstone and conglomerate. Sharp, typically planar base is basal surface of forced regression. Probable delta-associated deposits.

A PRELIMINARY SEQUENCE-STRATIGRAPHIC FRAMEWORK

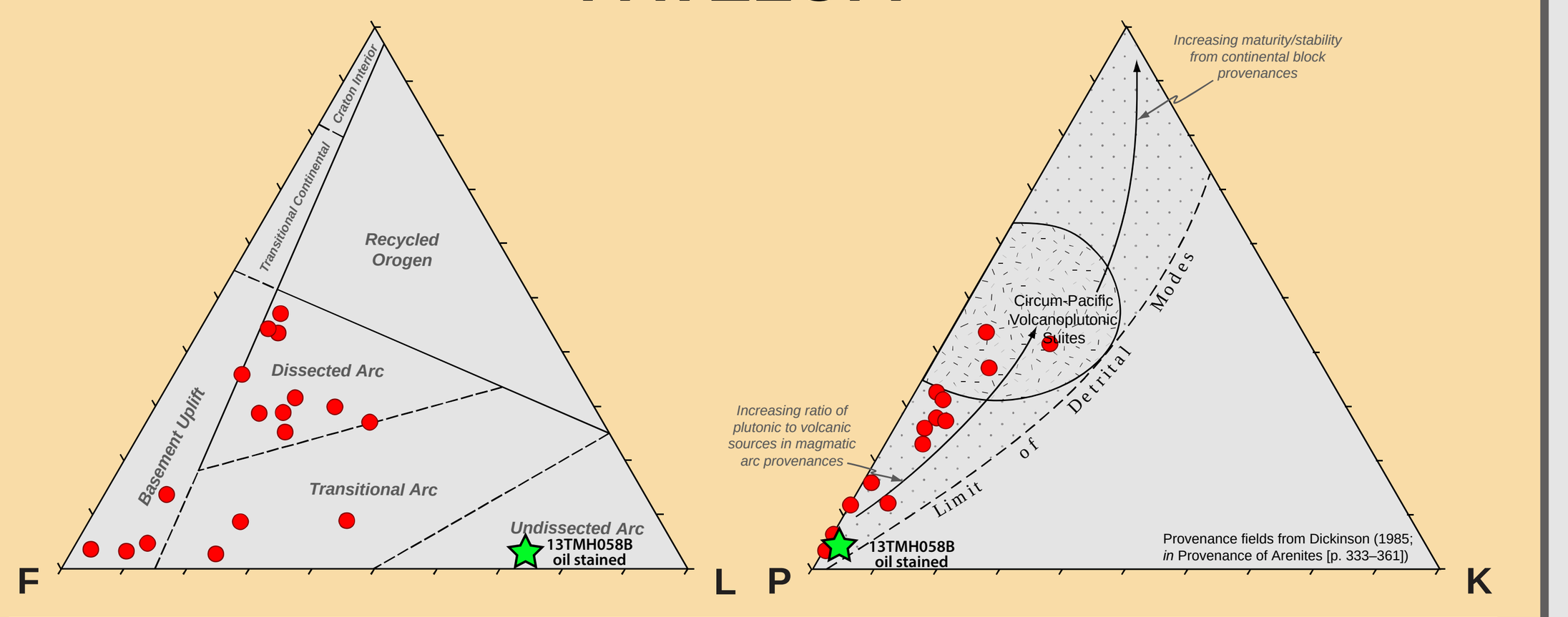


Jct₄—Coarsening- and thickening-upward succession of sandstone and siltstone. Sandstones locally channelized but dominantly tabular. Highstand deposits of possibly prodelta and delta settings.
Jct₃—Siltstone with subordinate sandstone. Locally onlaps Jct_2 along low-relief surface that may have formed via increased energy flux in outer(?)-shelf setting at onset of highstand regression. Maximum flooding surface likely at or below contact with Jct_2.
Jct₂—Thick, fining-upward succession of mainly siltstone. Lower part may record waning prodelta sedimentation as Jct_1 deltas were transgressed. Upper part may reflect outer-shelf sedimentation during continued transgression. Interval's base identified as transgressive surface.
Jct₁—Sandstone and conglomerate with subordinate siltstone. Interval is channelized in part. Unit's sharp base locally exhibits 10s of m erosional relief and is a sequence-bounding basal surface of forced regression. Deltaic(?) deposits, and may include shelf-valley-fill strata.
Photograph by T.M. Herriott.

KEY
- Basal Surface of Forced Regression
- HIGHSTAND SYSTEMS TRACT
- Maximum Flooding Surface
- TRANSGRESSIVE SYSTEMS TRACT
- Transgressive Surface
- LOWSTAND SYSTEMS TRACT
- Basal Surface of Forced Regresssion

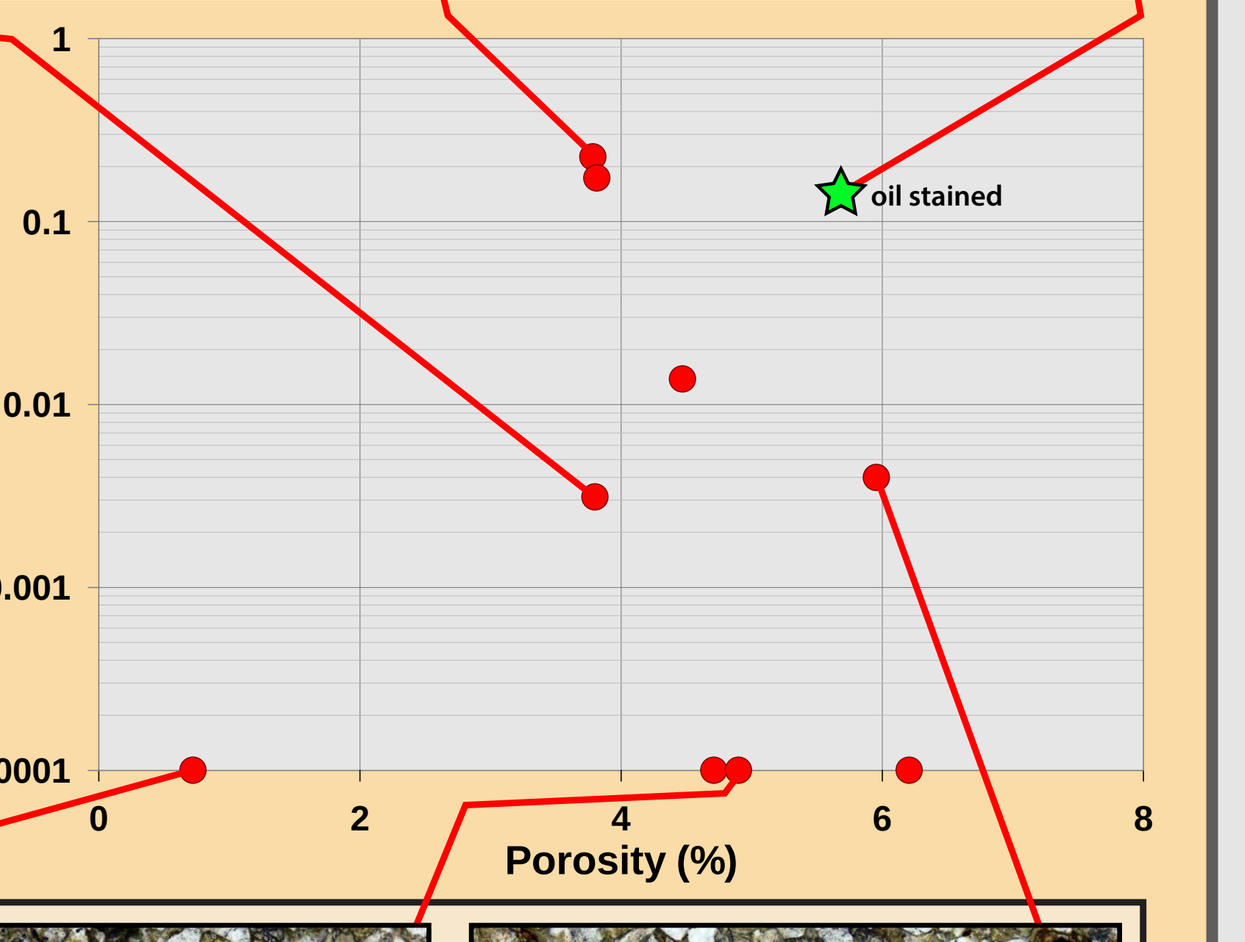
*Systems tracts after Posamentier and Allen (1999: SEPM Concepts in Sedimentology and Paleontology #7)

④ PETROLOGY AND RESERVOIR QUALITY: PAVELOFF



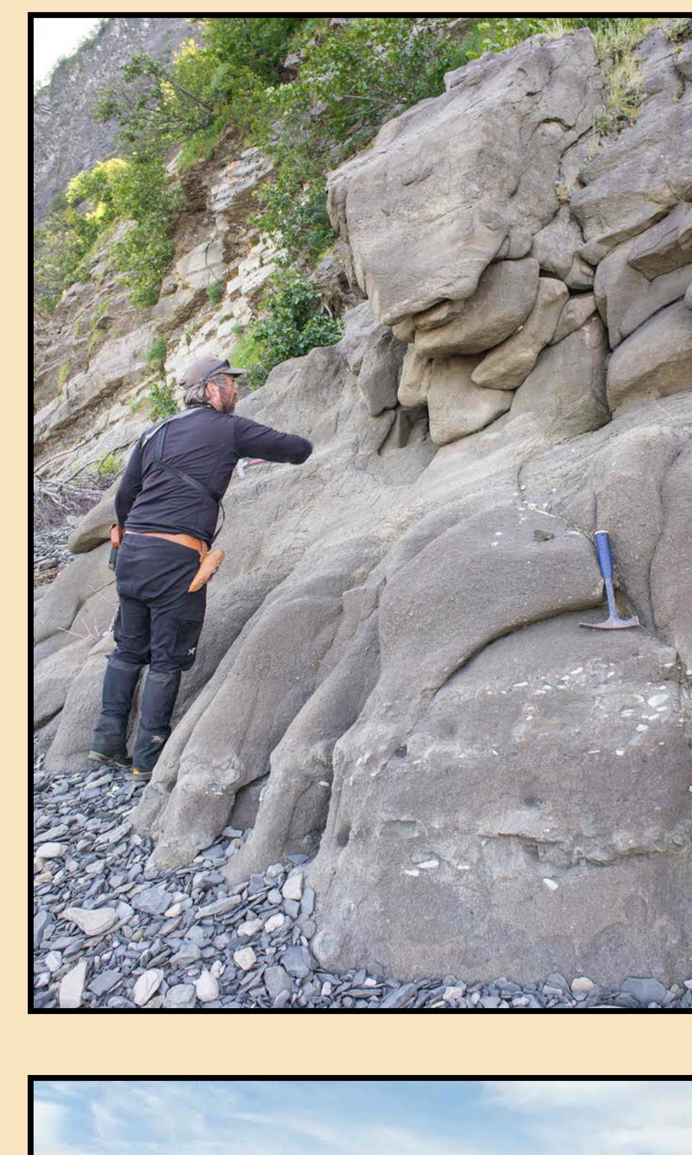
Paveloff Siltstone Mbr.—East shore Oil Bay	Paveloff Siltstone Mbr.—East shore Oil Bay	Paveloff Siltstone Mbr.—South shore Chinitna Bay
Φ = 3.8%; k = 0.0031 md	Φ = 3.8%; k = 0.225 md	Φ = 5.7%; k = 0.141 md
13A027-323.8A SEE 2.3	13A027-157.7A SEE 2.3	13TMH058B SEE 5

Sandstones in Paveloff Siltstone Member consist largely of calcic plagioclase (average 47%) that have been partially to totally albitized and lesser amounts of intermediate volcanic rock fragments (average 19%). Some grains are euhedral plagioclase crystals, suggesting derivation from relatively unconsolidated crystal tuffs. Grain sizes range from coarse silt to fine-grained sand through most of the Paveloff, but coarse- and very coarse-grained sandstones occur at the member's base. The sandstones are typically cemented by authigenic chlorite and lesser amounts of heulandite, resulting in poor reservoir quality. Some sandstones have substantial ferroan-calcite cement, with intergranular volumes approaching 40%, which suggests relatively early cementation. One coarse-grained sandstone from the south shore of Chinitna Bay (see photomicrograph at above right and locality **5** on map) is oil stained (see section **5**; also Wartes and Herriott [2015: doi: 10.14509/29533]) and cemented by extensive authigenic chlorite and patchy ferroan-calcite. This sample has nearly no porosity visible in thin section, and the hydrocarbon most likely resides in microporosity associated with the chlorite cement.



Paveloff Siltstone Mbr.—East shore Oil Bay	Paveloff Siltstone Mbr.—East shore Oil Bay	Paveloff Siltstone Mbr.—Tonnie Peak area
Φ = 0.7%; k = <0.0001 md	Φ = 4.9%; k = <0.0001 md	Φ = 6.0%; k 0.004 md
13A027-100.5A SEE 2.3	13A027-329.5A SEE 2.3	13PD024A SEE 2.2

⑤ OIL-STAINED OUTCROP: PAVELOFF



An oil-stained locality within lower Paveloff was discovered during a geologic mapping traverse along the south shore of Chinitna Bay (below). The hydrocarbon-bearing zone occurs immediately above the base of what is recognizable as Jcp_1 and comprises very-thick-bedded, structureless to faintly stratified, coarse-grained sandstone (left and right) with common "floating" granules (right). Sedimentary textures and stratification of the interval suggest deposition from dense, laminar flows was common. Wartes and Herriott (2015: doi: 10.14509/29533) preliminarily interpreted these strata as delta-front deposits that accumulated during an episode of high sediment supply. Reservoir quality parameters of the oil-stained sample are among the best known from Paveloff (see section **4**), suggesting that down-dip equivalents to Jcp_1 may host accumulations of oil and should be considered within the context of Mesozoic play concepts in Cook Inlet. Photographs by T.M. Herriott.