The Structure of the Wrangel Arch (Russian Chukchi Sea), Based on Marine Seismic and Onshore Observations*

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Abstract

Wrangel Arch represents the extensive (more, than 500 km) ~ E-W trending offshore basement high, separating the well-known shelf depressions: North and South Chukchi (Hope) sedimentary basins, filled by more than 16-18 km of Late Paleozoic(?)-Tertiary and up to 5-6 km of Aptian(?)-Tertiary sequences, respectively. The onshore exposures of the Arch are known on Cape Lisbourne (Alaska) and on Wrangel Island in the Russian sector.

Our study of the Arch is based on the TGS 2D seismic data of a 2006 survey in the Russian Chukchi Sea and onshore geological observations on the Central and Western parts of the Wrangel Island. It is likely that the Wrangel Arch represents the northwestern extension of the Herald Arch-Lisburne Hills fold belt. Wrangel Island is mostly composed of Neoproterozoic metamorphic rocks and uncomfortably overlying Paleozoic-Triassic sedimentary sequences involved in the Late Kimmerian rather uniform North-vergent fold and thrust deformation.

Seismic data revealed intensive development of both the North- and South-vergent thust sheets of the Wrangel Arch. The geological complexes of the Island are the key issues for investigating the structure, tectonics and hydrocarbon potential of the Russian Eastern Arctic Shelf, including the folded basement of the South Chukchi and lower (Ellesmerian) sequences of the North Chukchi Basin.

Undeformed Turonian(?)-Tertiary sandy-clayey strata, known for the northernmost exposures of Wrangel Island, are the age-equivalent of the uppermost Lower and Upper Brookian sequences and thus correspond to the upper part of the sedimentary cover of

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the North Chukchi Basin and the main sedimentary infill for the South Chukchi Basin, which is not older than Aptian-Albian. The structural pattern of the northern front of the Arch is heterogeneous. The series of North-vergent thrust faults, with the main detachment at the base of Brookian were detected. On the other hand, obvious double-vergent pop-up and positive flower (dextral(?) transpressional) structures of Early Paleocene age were also observed. We relate the latest N-S to NE-SW extensional stage to the formation of the South Chukchi Basin and the series of small half-grabens superimposed on the Wrangel Arch. The integrated approach to the research of the Wrangel Arch by marine seismic and onshore geological-analytical methods is crucial for the exploration of the offshore sedimentary basins of Chukchi and adjoining East Siberian Sea.

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The Structure of the Wrangel Arch (Russian Chukchi Sea), Based on Marine Seismic and Onshore Observations

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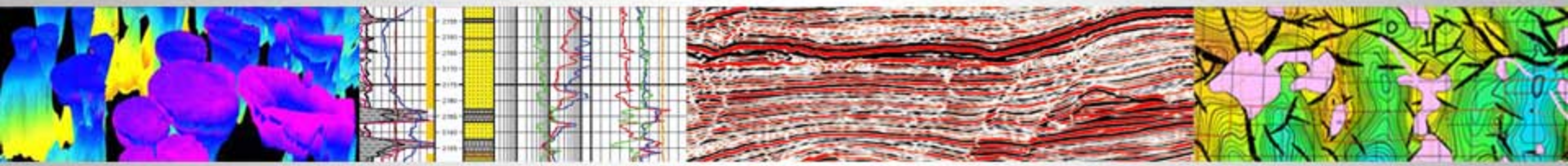

AAPG International, Calgary, September 2010

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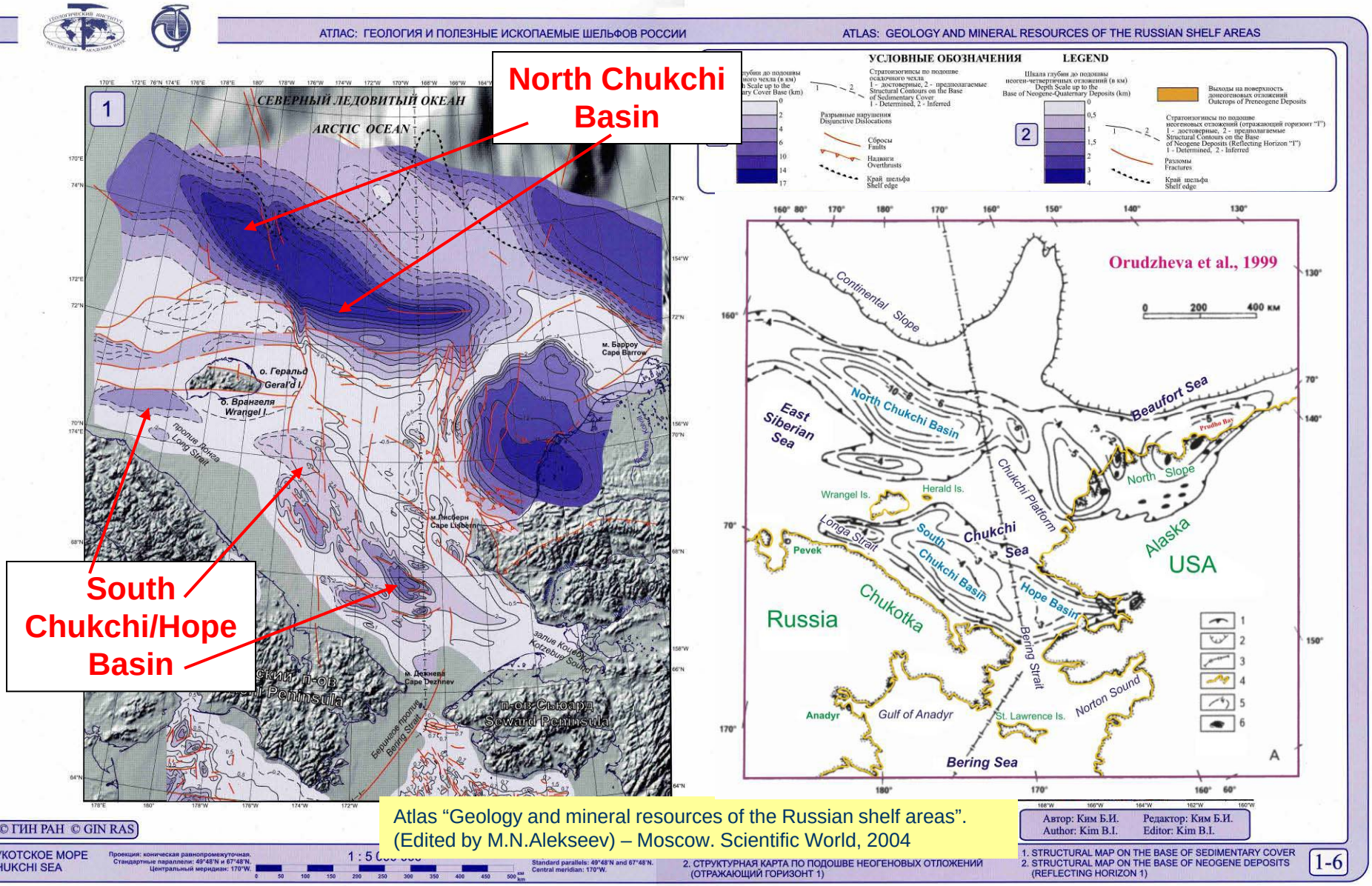
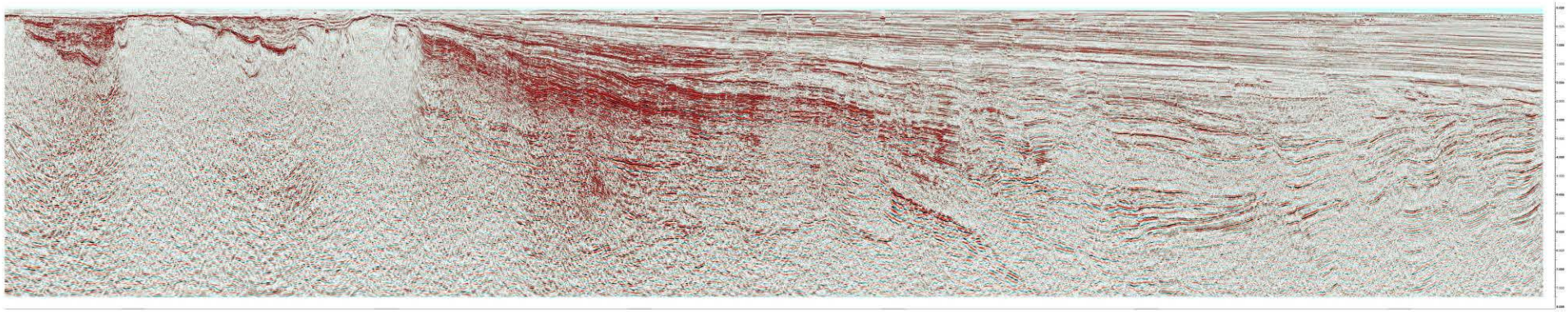
Chukchi Sea: the Structure of Sedimentary Cover



The structure of South Chukchi basin – Wrangel Arch – North Chukchi basin

Wrangel Kimmerian Arch (deformed Pr_2-T)

North Chukchi sedimentary basin (D_3-Cz)



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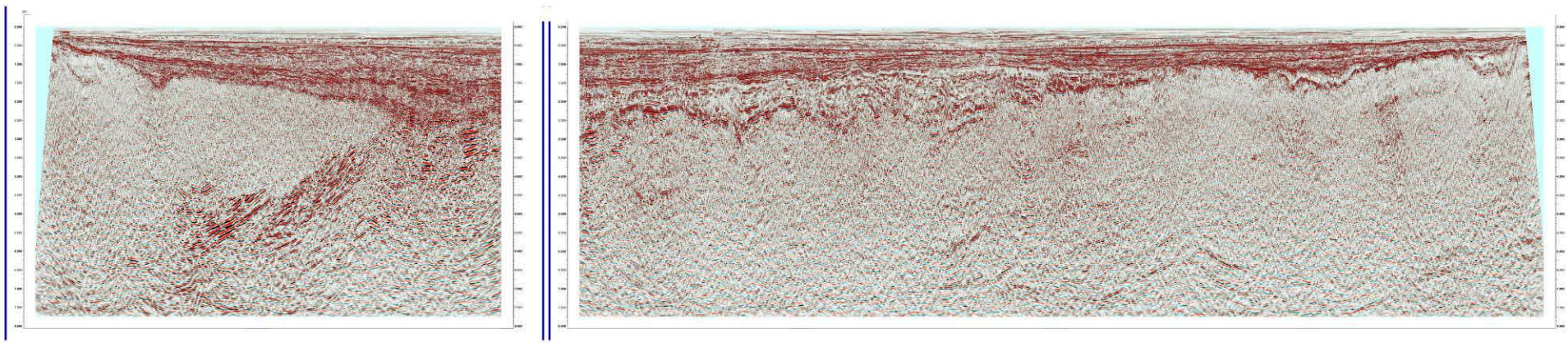
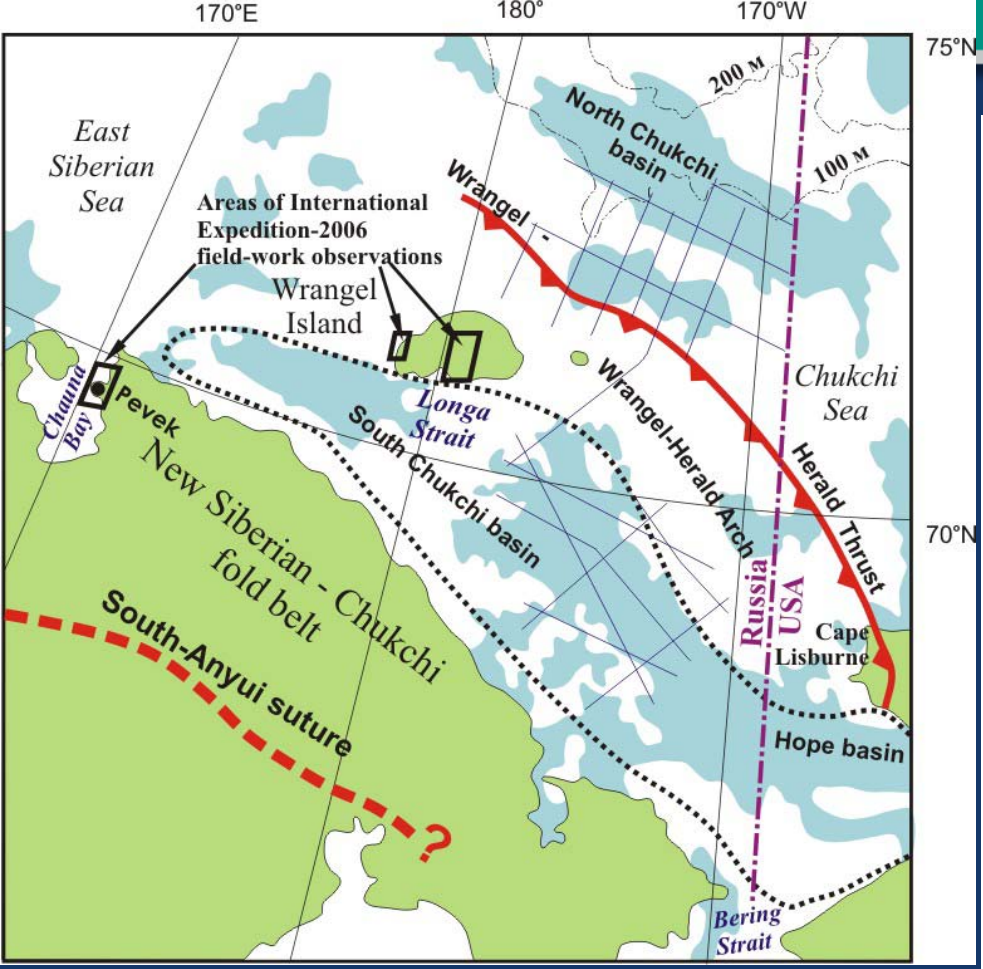
~10 km

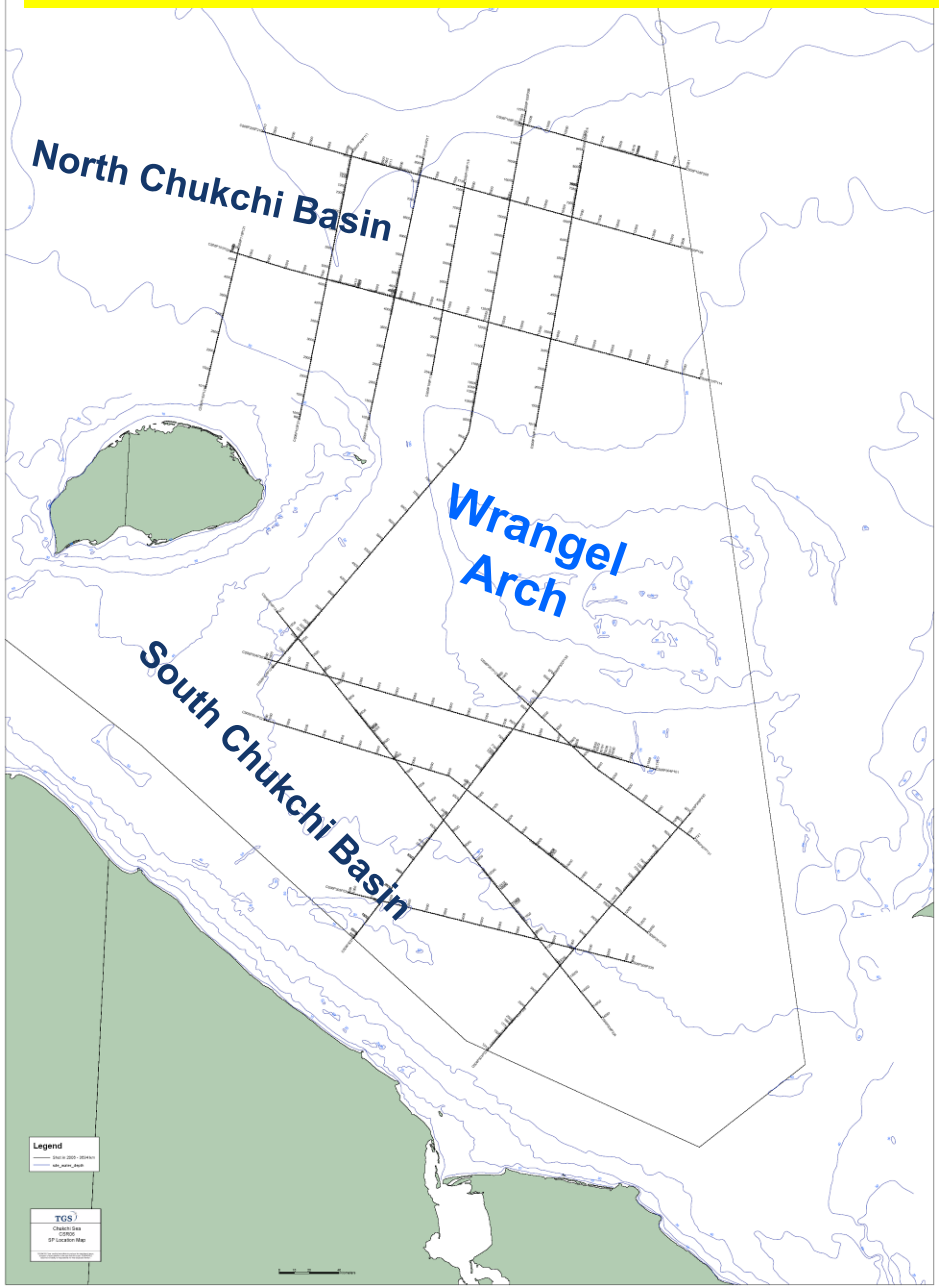
South Chukchi sedimentary rifted basin (K_2-Cz), inherited Late Kimmerian collisional structural pattern





Main tectonic elements of Chukchi Sea region. Compiled after [*Mazarovich., Sokolov, 2003; Khain, 2001; Sokolov et al,, 2001, 2002; Miller et al., 2002*]. Blue color corresponds to the simplified distribution of free air gravity anomalies.

TGS/Geophysical Solutions Integrator MC survey in Chukchi Sea (2006)



International Expedition
“Wrangel Island and Northern Chukotka” 2006

Sergey Sokolov

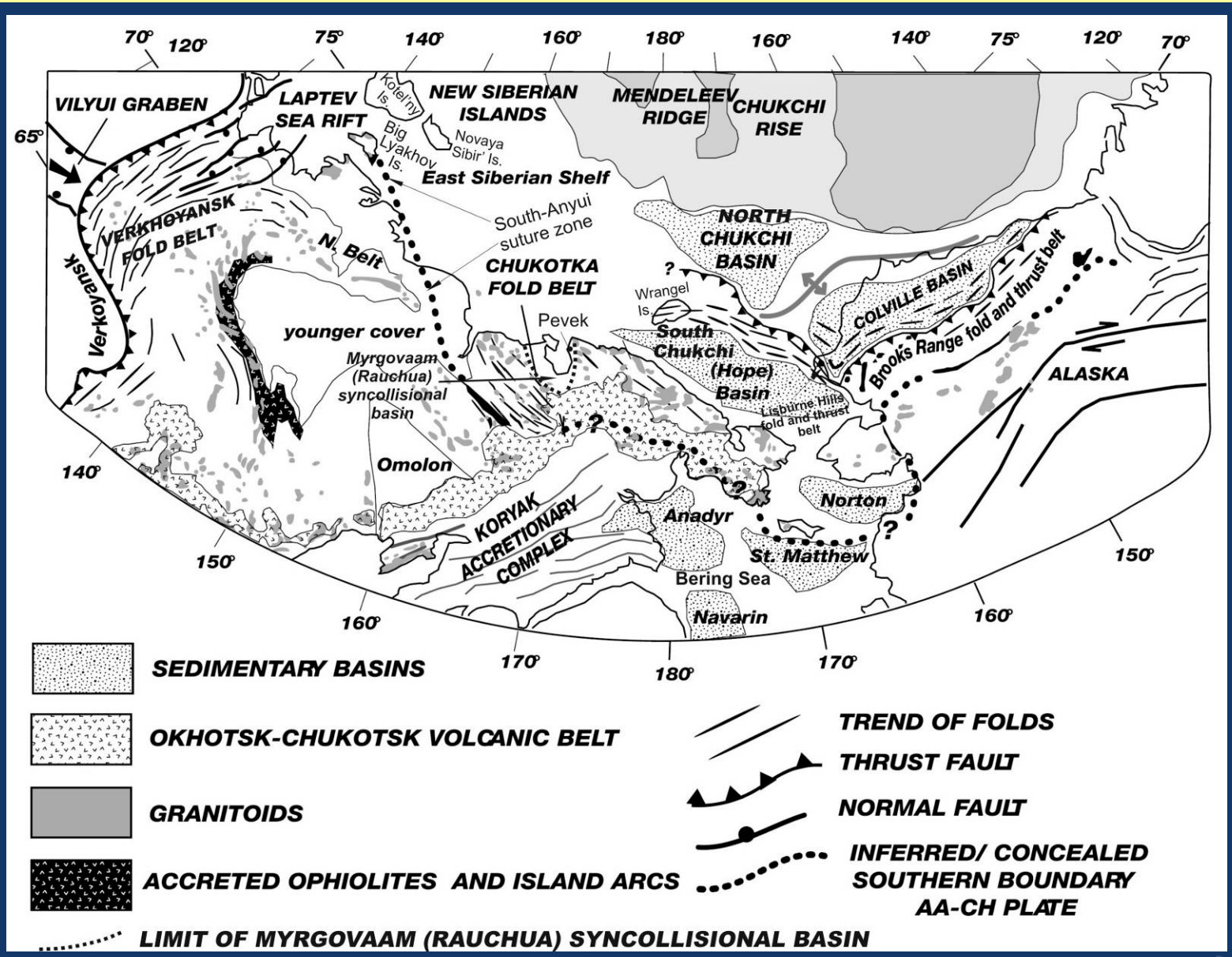
Elizabeth Miller

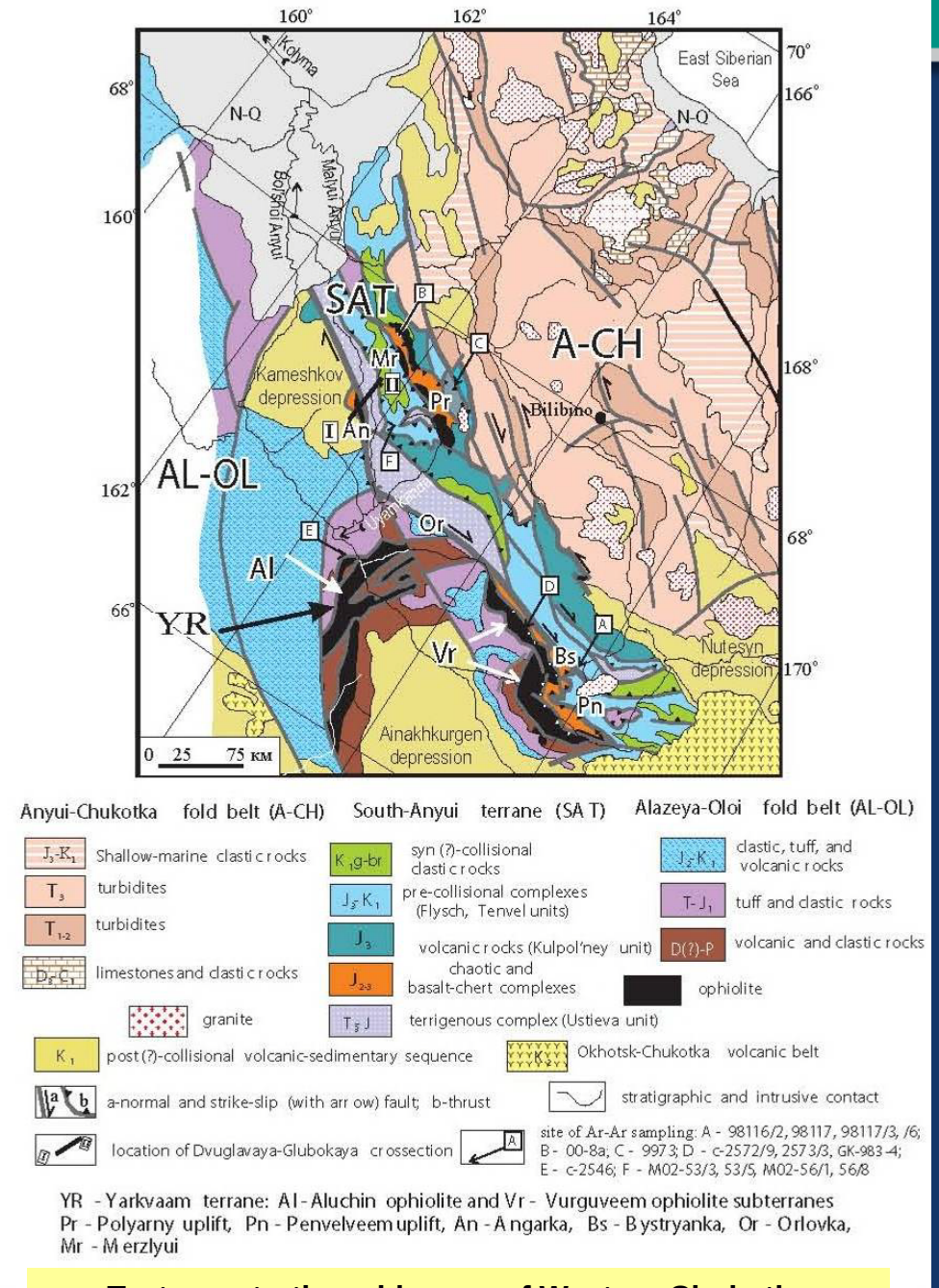
Marianna Tuchkova

Victoria Pease

Vladimir Verzhbitsky

Tectonic map of the main Mesozoic structural belts of north-east Arctic Russia and northern Alaska. *Modified after Miller et al. (2006).*

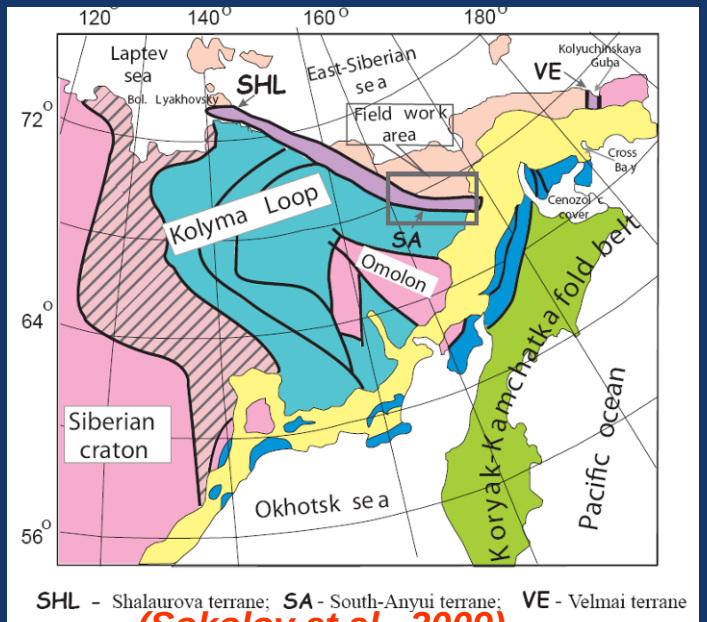




Tectono-stratigraphic map of Western Chukotka

(Sokolov et al., 2009)

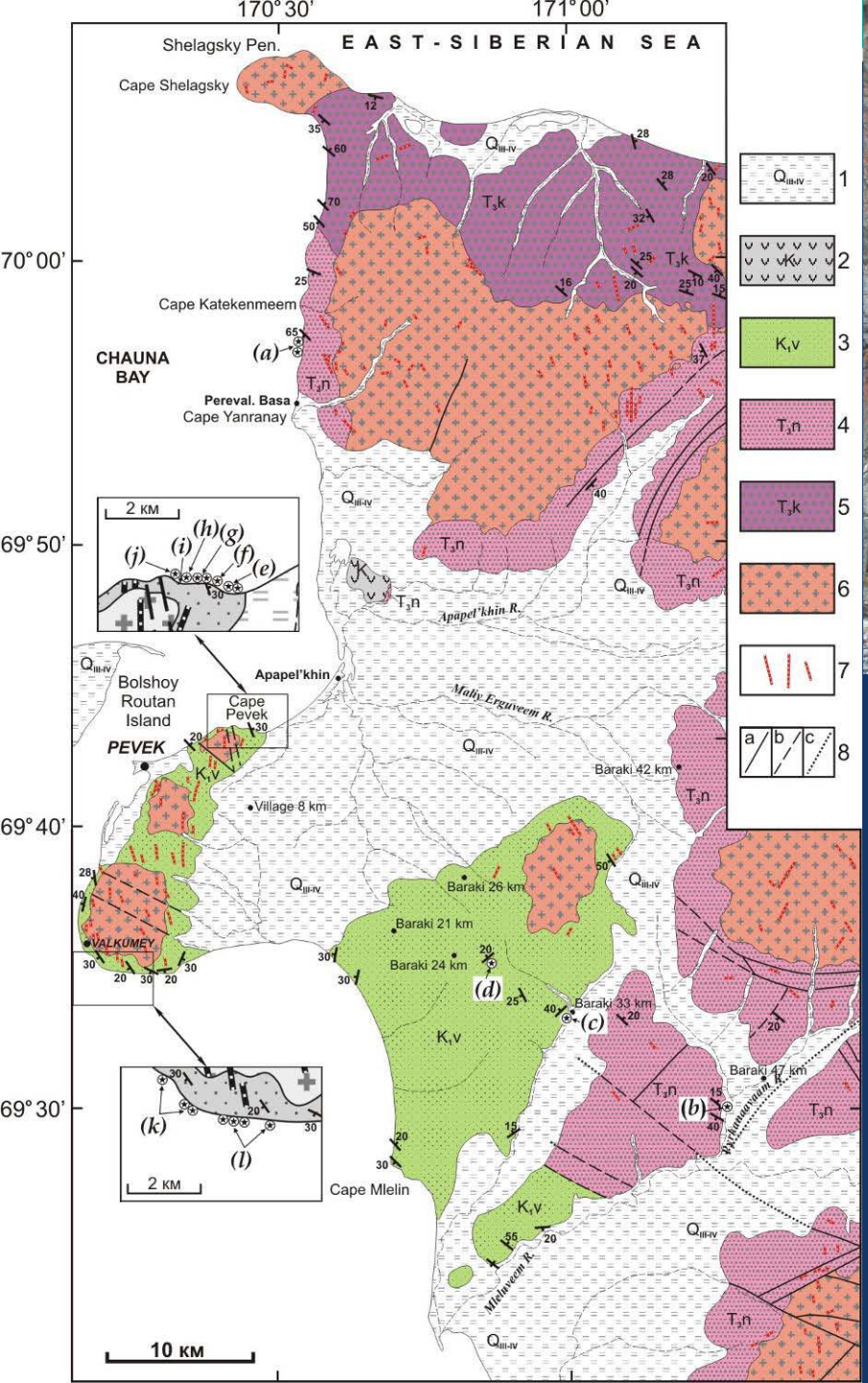
Pre-Aptian regional unconformity

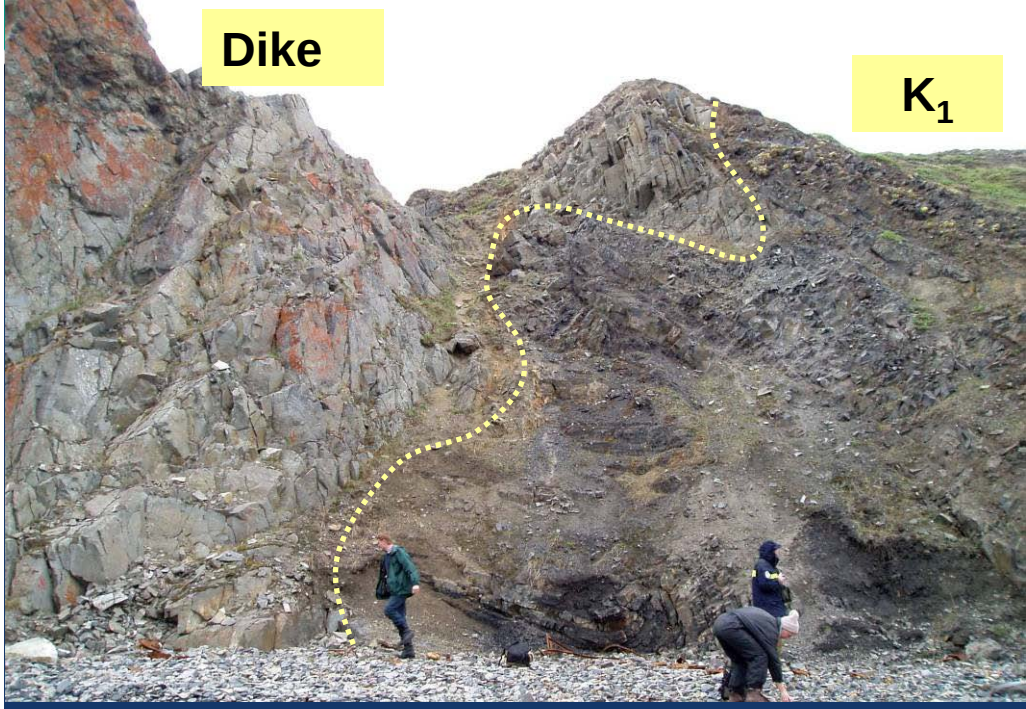


(Sokolov et al., 2009)

Fig. 1. Tectonic scheme of Northeastern Russia.

The collisional stage spanned a rather wide age range from the Neocomian to the Aptian (Parfenov, 1984; Natal'in, 1984; Sokolov et al., 2001, 2002). Structural studies have established the following time series of tectonic deformations:
(i) north vergent thrusts and nappes (subphase D2 −1),
(ii) south vergent thrusts and folds (subphase D2 −2), and
(iii) late collisional dextral strike-slips (subphase D2−3).
The North vergent thrusting took shape during the Hauterivian–Barremian (Sokolov et al., 2001, 2002), and the **Aptian–Albian stage, in the course of which the Ainakhkurgen, Kameskov, and Nutesyn basins formed. These are filled in with slightly deformed sedimentary and volcanic deposits, overlapping with sharp angular unconformity all principal tectonic features of western Chukotka.**
Dextral strike-slip faults deform the coarse clastic deposits of Barremian–Aptian age, and do not deform upper Albian effusives of OCVB. For this reason, the time of postcollisional dextral strike slip motion may be constrained to the Barremian–Aptian (possibly, early Albian) interval.





Postcollisional Aptian-Albian granites, ~117-108 Ma

(Katkov et al., 2007; Miller et al., 2009).

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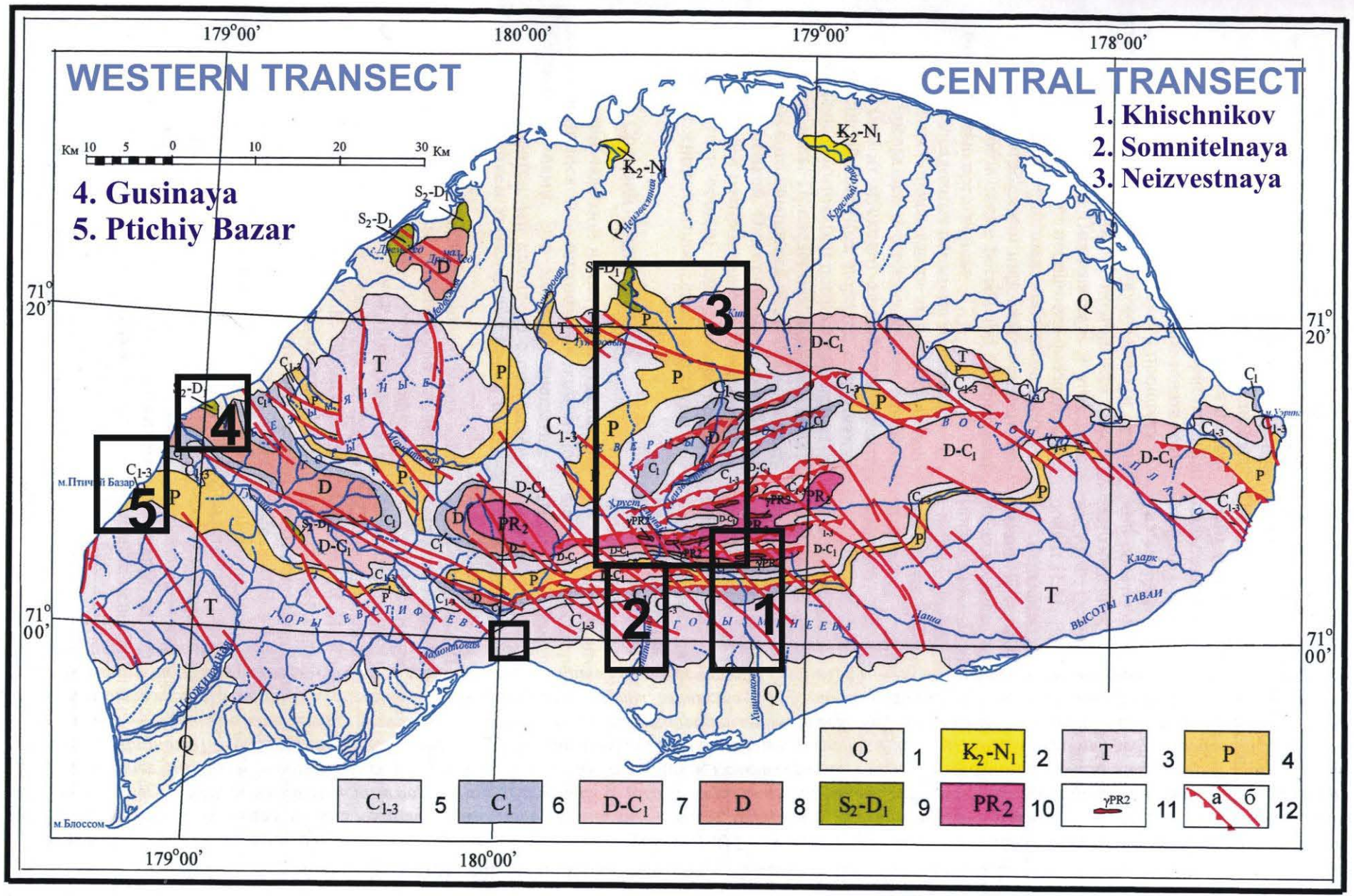
South of Pevek: The base of the Northern segment of OCVB, ~ 106 Ma- K_1 Albian (Tikhomirov et al., 2008) is a regional unconformity and volcanic rocks above are close to <u>flat-lying</u>.

Geological Map of Wrangel Island (Kos'ko et al., 1993, 2003).

Superimposed are the areas of field work investigations of International Expedition 2006.



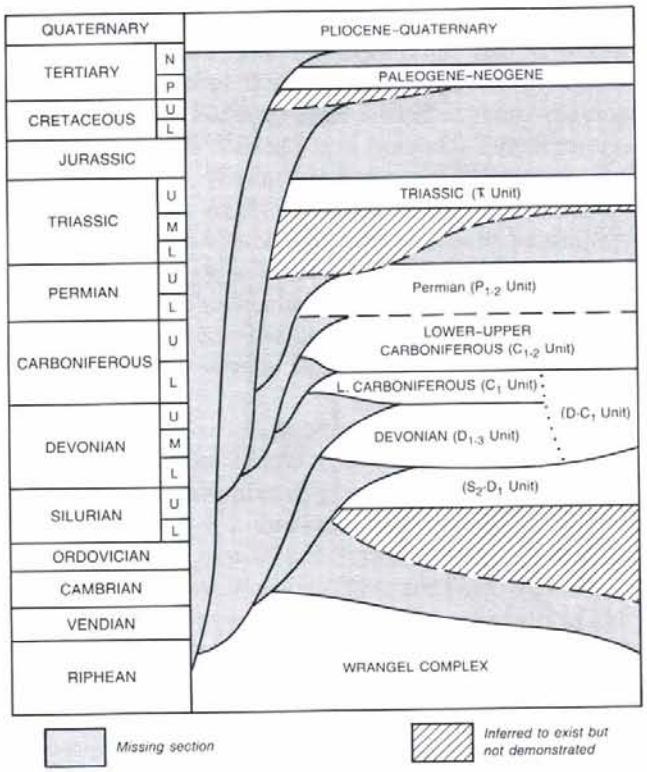


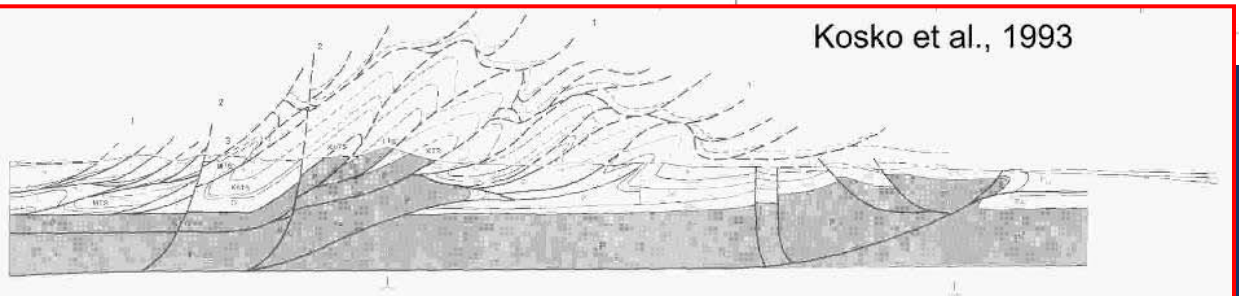
Figure 10. General stratigraphic scheme.

TABLE 1

Stratigraphy of Wrangel Island

Age	Unit	Lithology
Quaternary	Unnamed	Coarse clastic alluvium, proluvium, eluvium and colluvium.
Late Tertiary	Unnamed	Indurated Pliocene mud and gravel (a few metres).
Tertiary Paleogene–Neogene	PN	Clay and gravel (a few tens of metres thick).
Triassic	T	Black to dark grey argillaceous quartz turbiditic sandstone with minor feldspar and lithic fragments, black slate; minor siltstone (total thickness estimated to be 800–1500 m).
Permian	P_{1-2}	Slate and limestone with minor sandstone, coarse clastic and siliceous strata; in the north the basal part contains a thick olistostrome-breccia succession (up to 750 m thick).
Carboniferous	C_{1-2}	Two facies types: 1) microcrystalline and crinoidal biocalcarenite, fine grained, thin bedded limestone, and minor slate and argillite; 2) limestone interstratified with slate and argillite (up to 1400 m thick).
Lower Carboniferous	C_1	Clastic rocks, including intrabasinal conglomerate, slate, argillite, with gypsum and carbonate (up to 350 m thick).
Devonian	D_{1-3}	Immature clastic rocks, including sandstone, argillite, slate and conglomerate (as much as 1200 m thick).
Silurian–Devonian	S_2D_1	Fossiliferous quartzose sandstone, siltstone, slate, carbonate (total thickness = 700 m)
Upper Proterozoic	Wrangel Complex	Felsic to intermediate volcanic and volcaniclastic rocks, sericitic and chloritic slate/schist with minor grey and black slate, and very minor mafic metavolcanics, quartzite, and metaconglomerate; intruded by quartz–feldspar porphyry, metagabbro, metadiabase, and aplitic felsic dykes and sills and small elongate granitic and aplitic intrusive bodies (total thickness = >2000 m).

Stratigraphy, lithology and structural pattern of Wrangel Island



Kosko et al., 1993

(Kos'ko et al., 1993; 2003)

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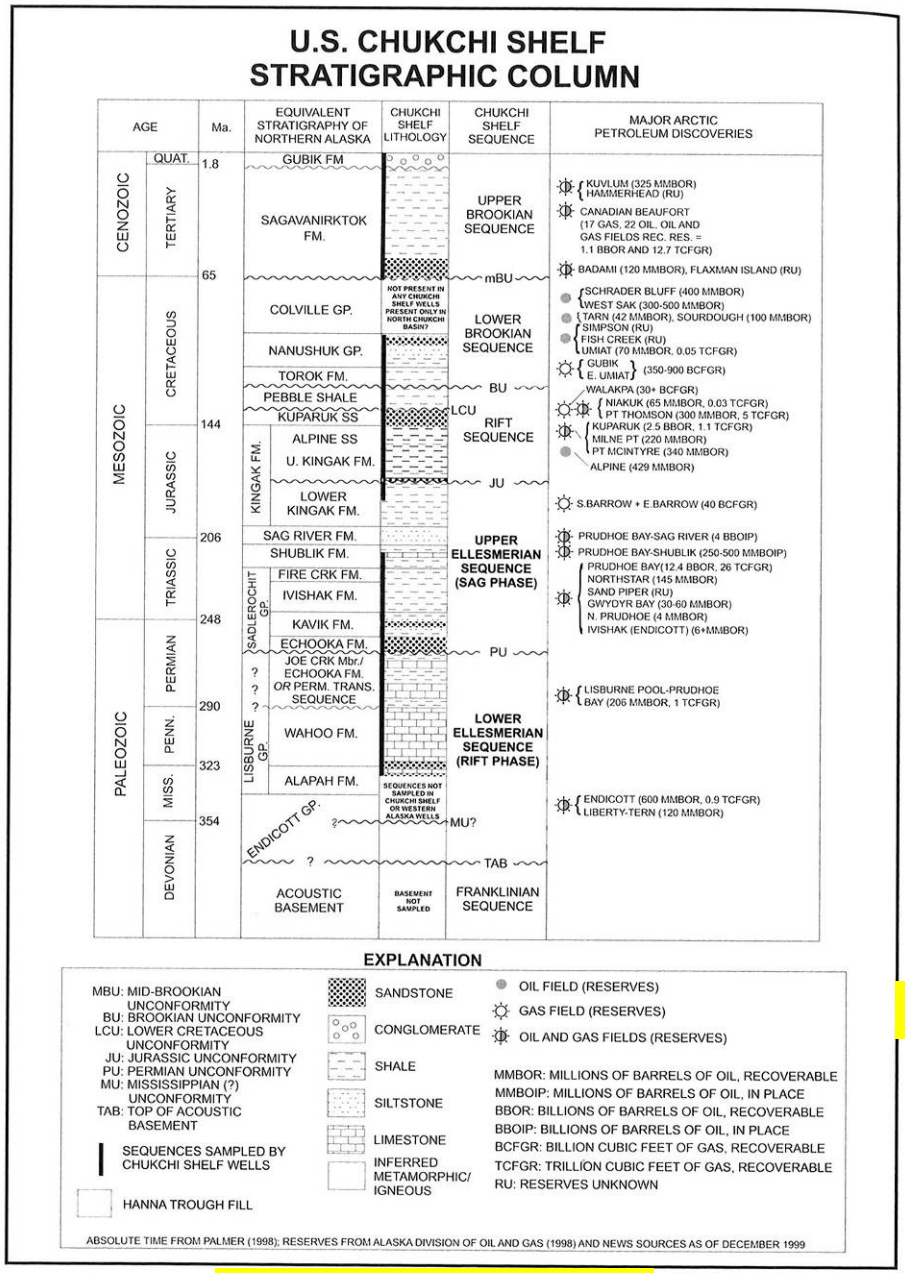
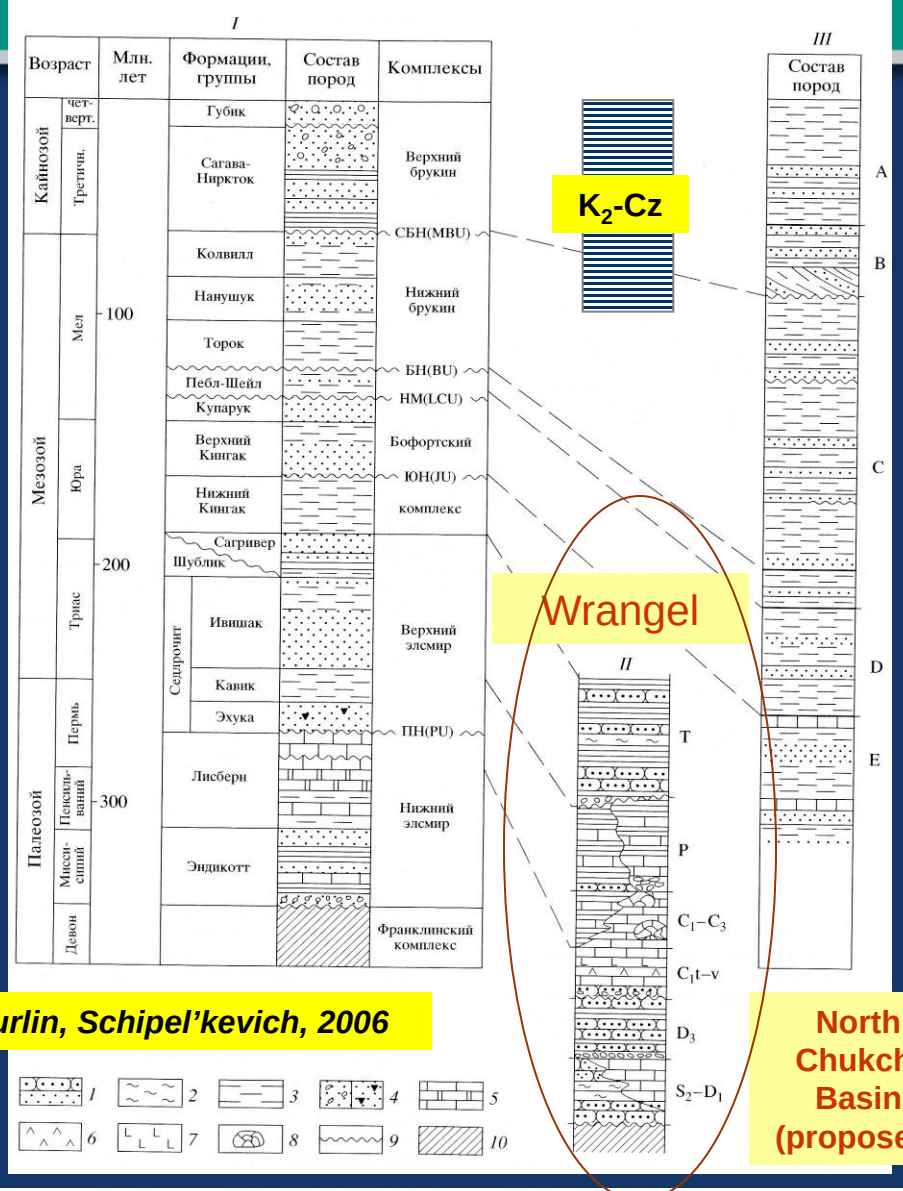


Sherwood et al, 2002



Burlin, Schipel'kevich, 2006

North Chukchi Basin (proposed)

Рис. 2. Схематические стратиграфические разрезы отложений в северо-западной части Аляски (*I*) и сопоставление с разрезом о. Врангеля (*II*), предполагаемым разрезом Северо-Чукотского прогиба (*III*)

1 – песчаные породы; *2* – алевритовые породы; *3* – глинистые породы; *4* – грубообломочные породы; *5* – карбонатные породы; *6* – эвапоритовые породы; *7* – вулканические породы; *8* – рифовые массивы; *9* – перерывы и несогласия; *10* – интенсивно дислоцированные отложения. Сокращения на схеме: СБН (MBU) – среднебрукинское несогласие, БН (BU) – брукинское несогласие, НМ (LCU) – нижнемеловое несогласие, ЮН (JU) – юрское несогласие, ПН (PU) – пермское несогласие. A–E – буквенные обозначения сейсмокомплексов на колонке, соответствующих: A – верхнему брукину, B – выполняющих неровности после перерыва, C – нижнему брукину, D – отложениям между брукинским и юрским несогласиями, E– отложениям ниже юрского несогласия

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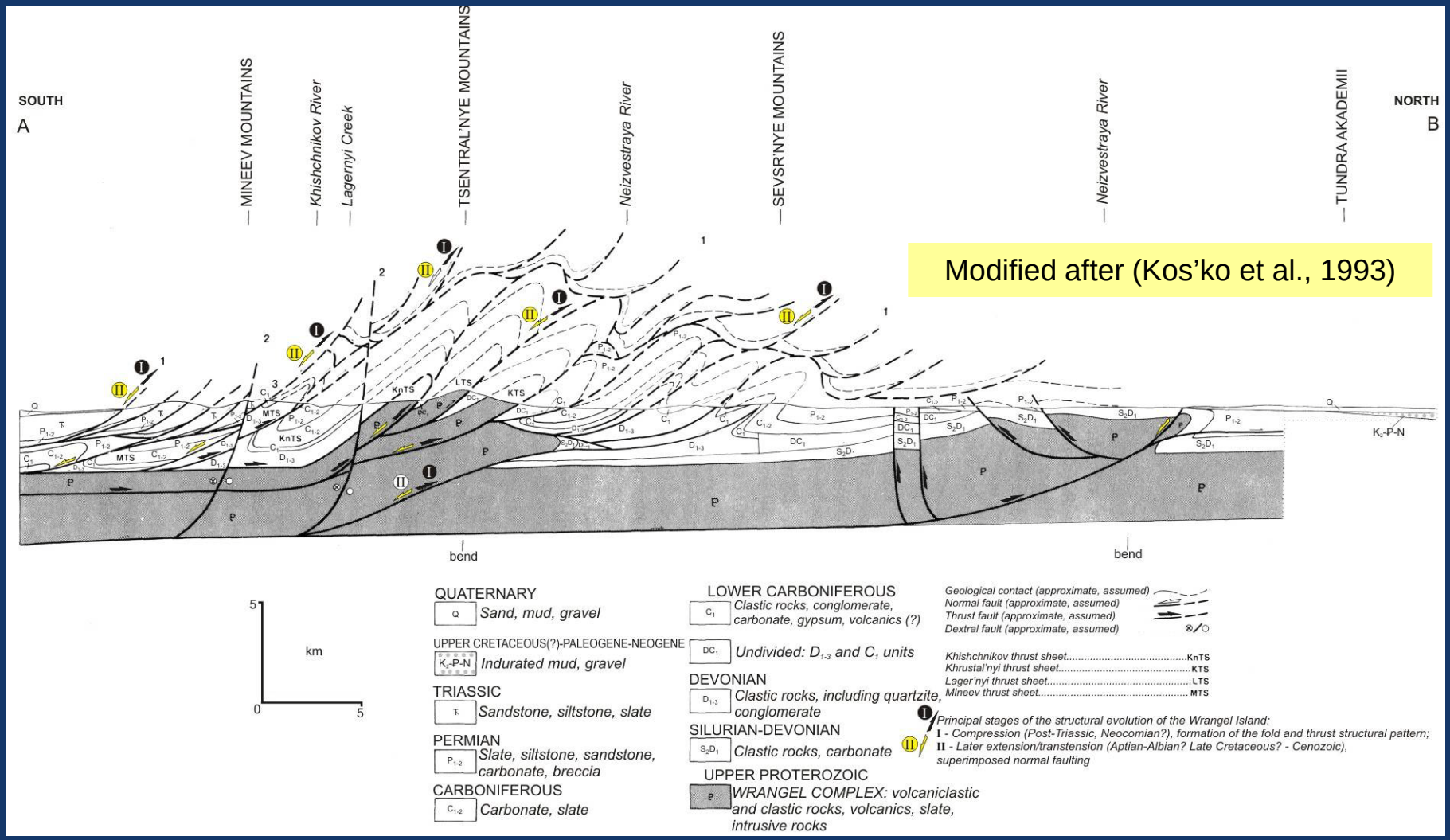
Wrangel Island:

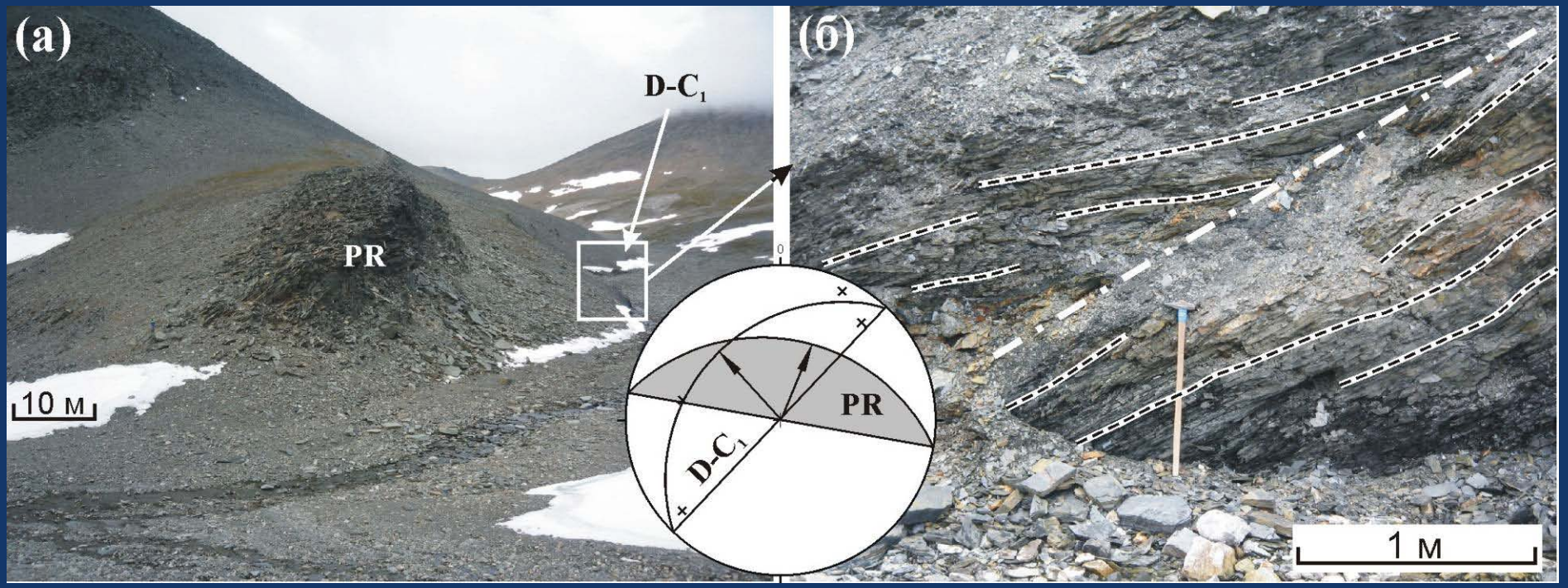
example of north-vergent fold and thrust fault structural pattern



Schematic structural cross-section through central Wrangel Island, modified after Kos'ko et al. (1993, 2003), using some results of our fieldwork.

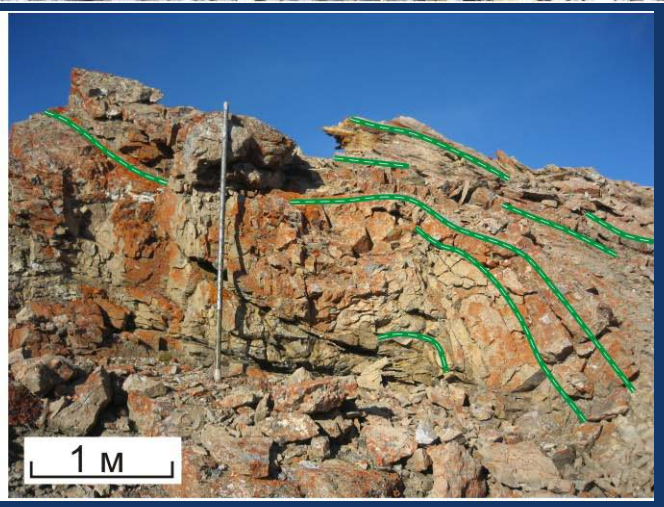
Wrangel Island:

example of north-vergent fold and thrust fault structural pattern



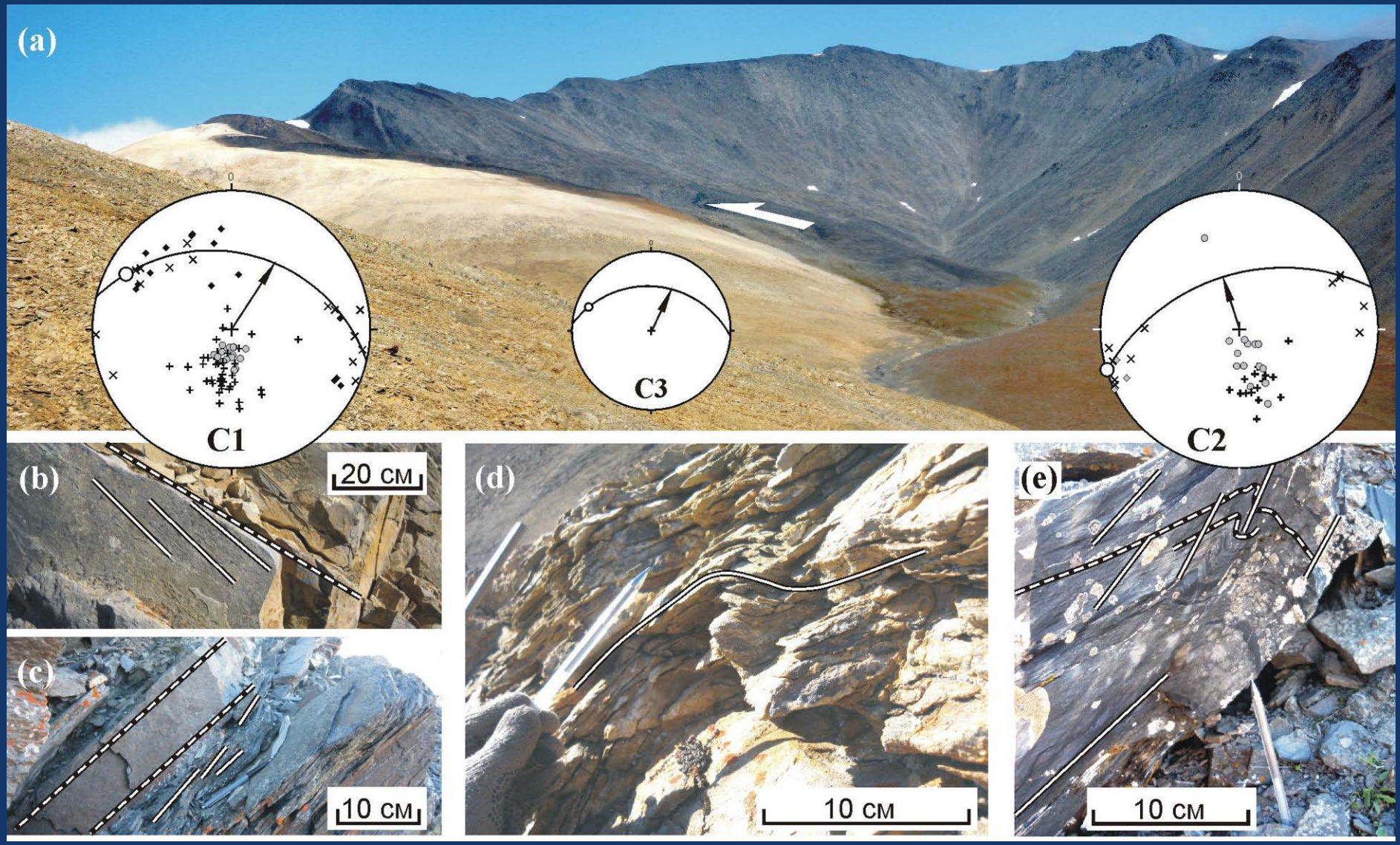
stereonets:

equal angle projection, upper hemisphere

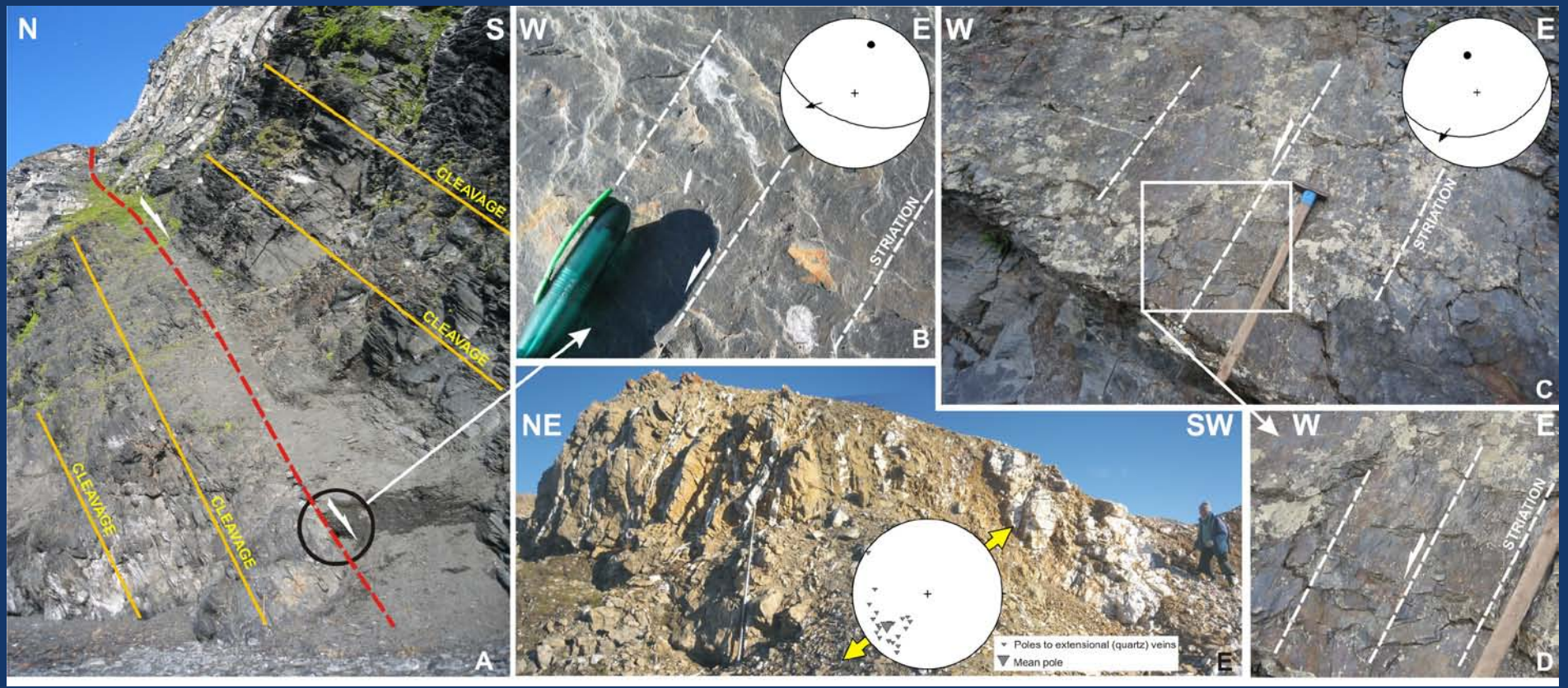


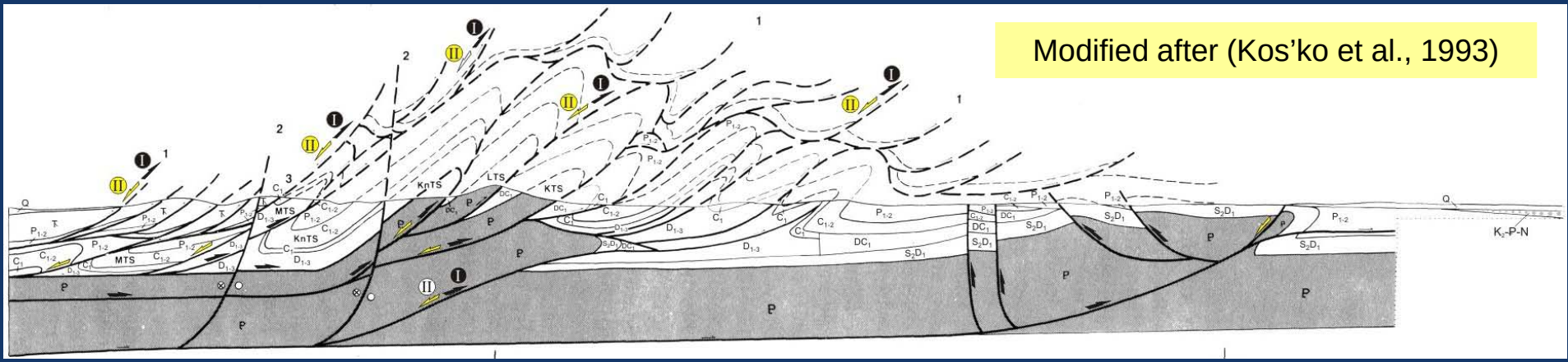
Wrangel Island:

example of north-vergent fold and thrust fault structural pattern



Superimposed extensional/dextral transtensional structures





Modified after (Kos'ko et al., 1993)

Late Mesozoic Chukotkian collisional deformation is do continuing into Chukchi Sea offshore

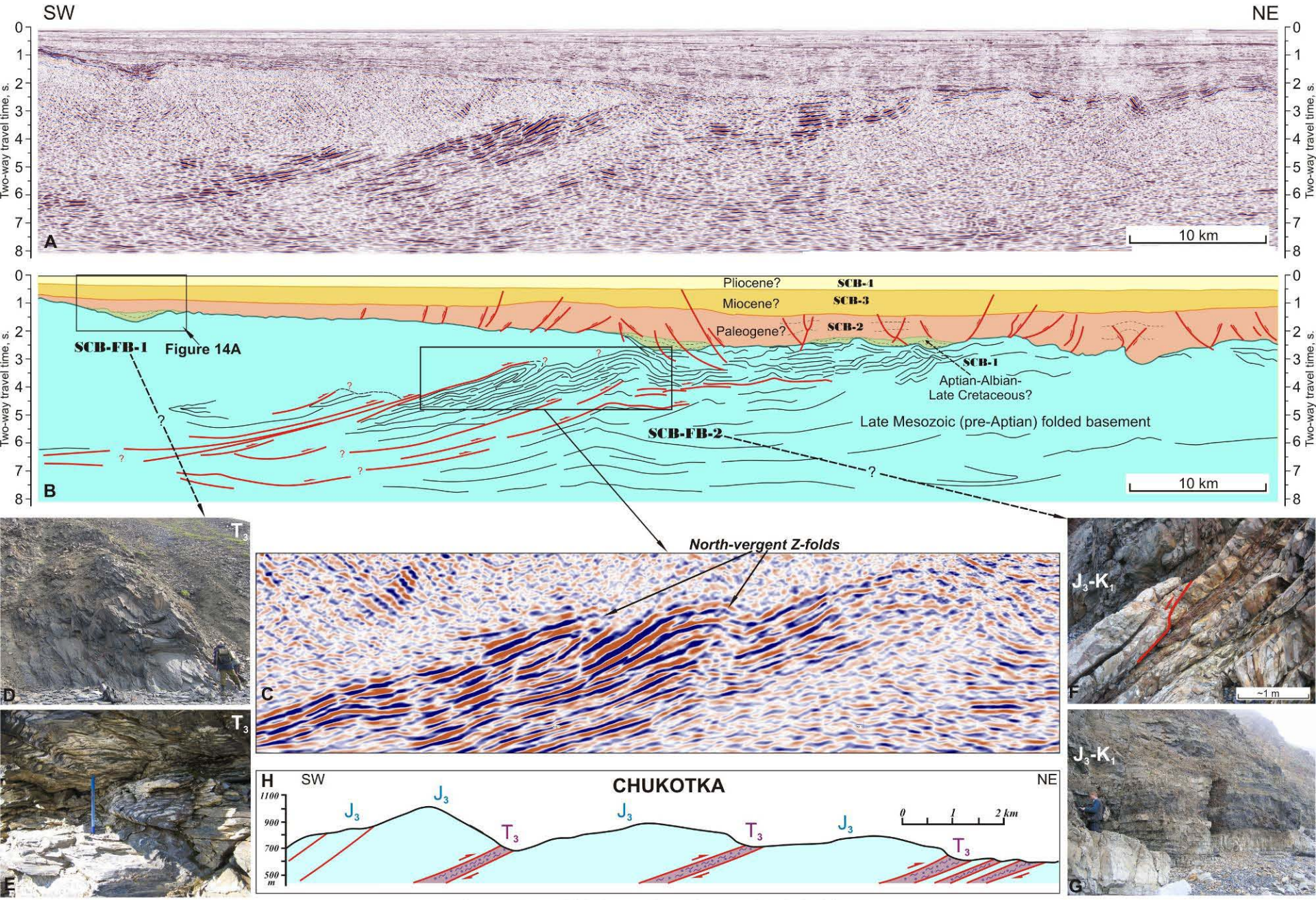
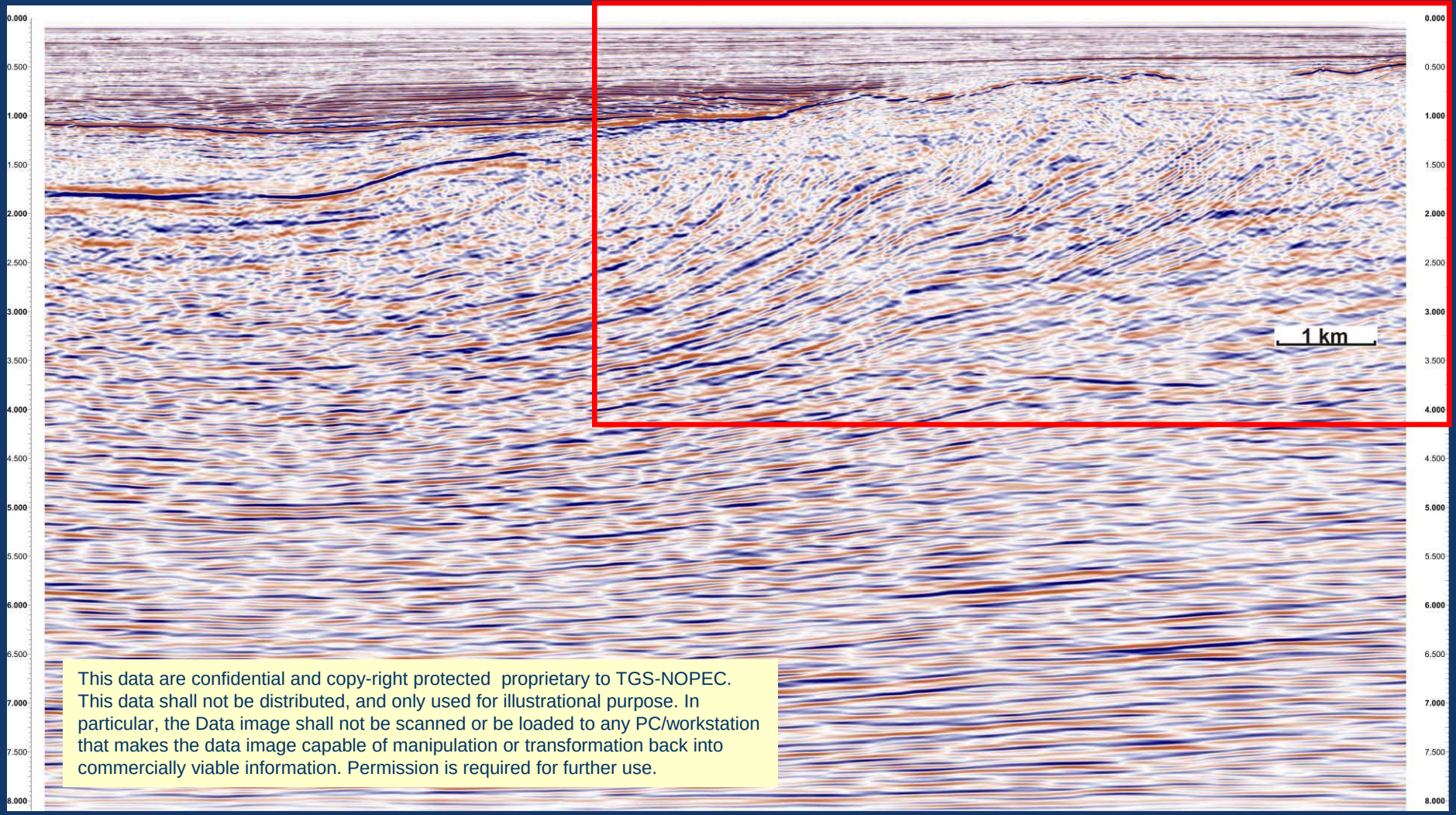


Figure 9, Verzhbitsky et al., "The South Chukchi…"

Wrangel Arch:

example of north-vergent fold and thrust fault structural pattern



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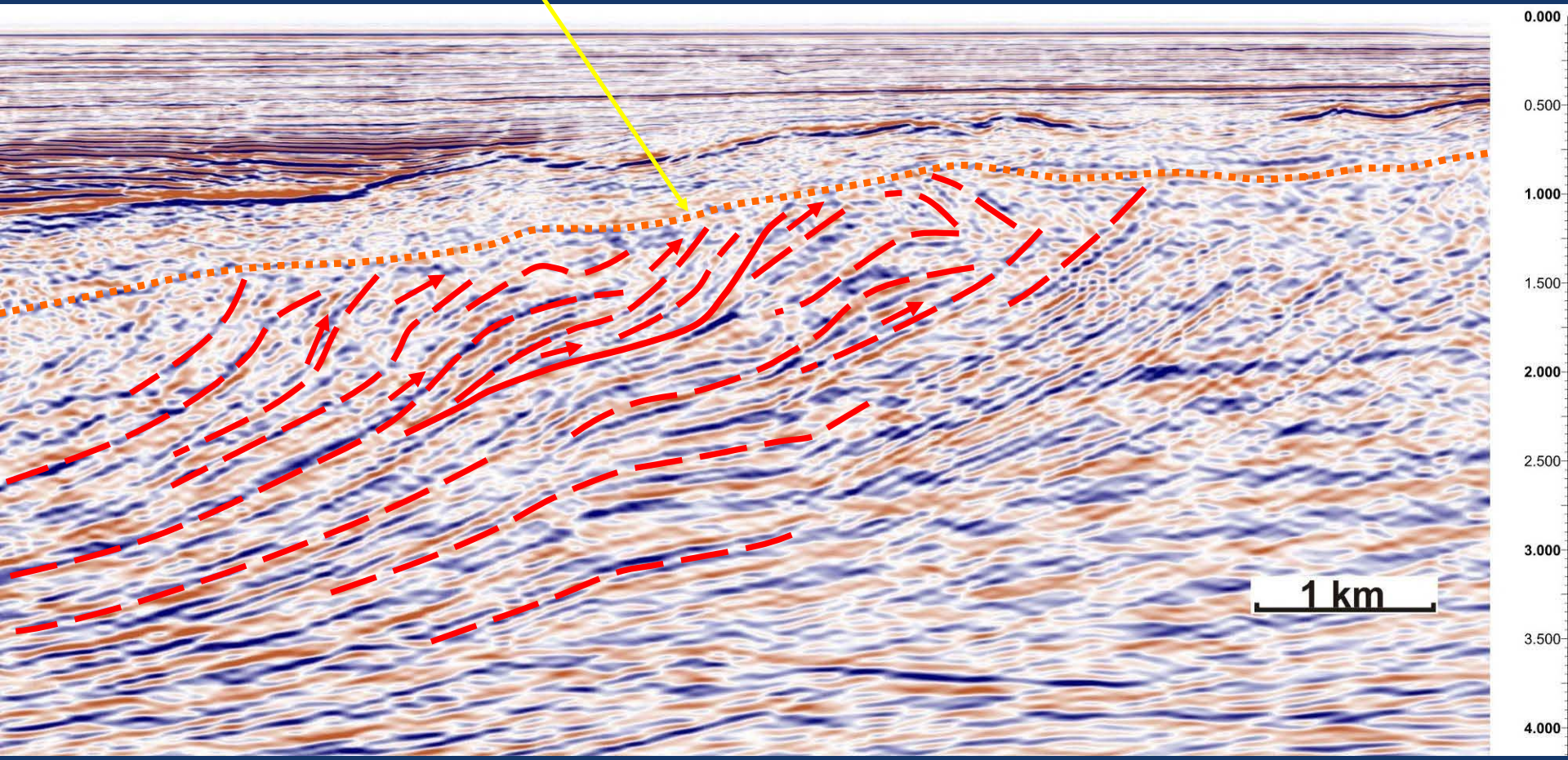
Wrangel Arch: example of north-vergent fold and thrust fault structural pattern



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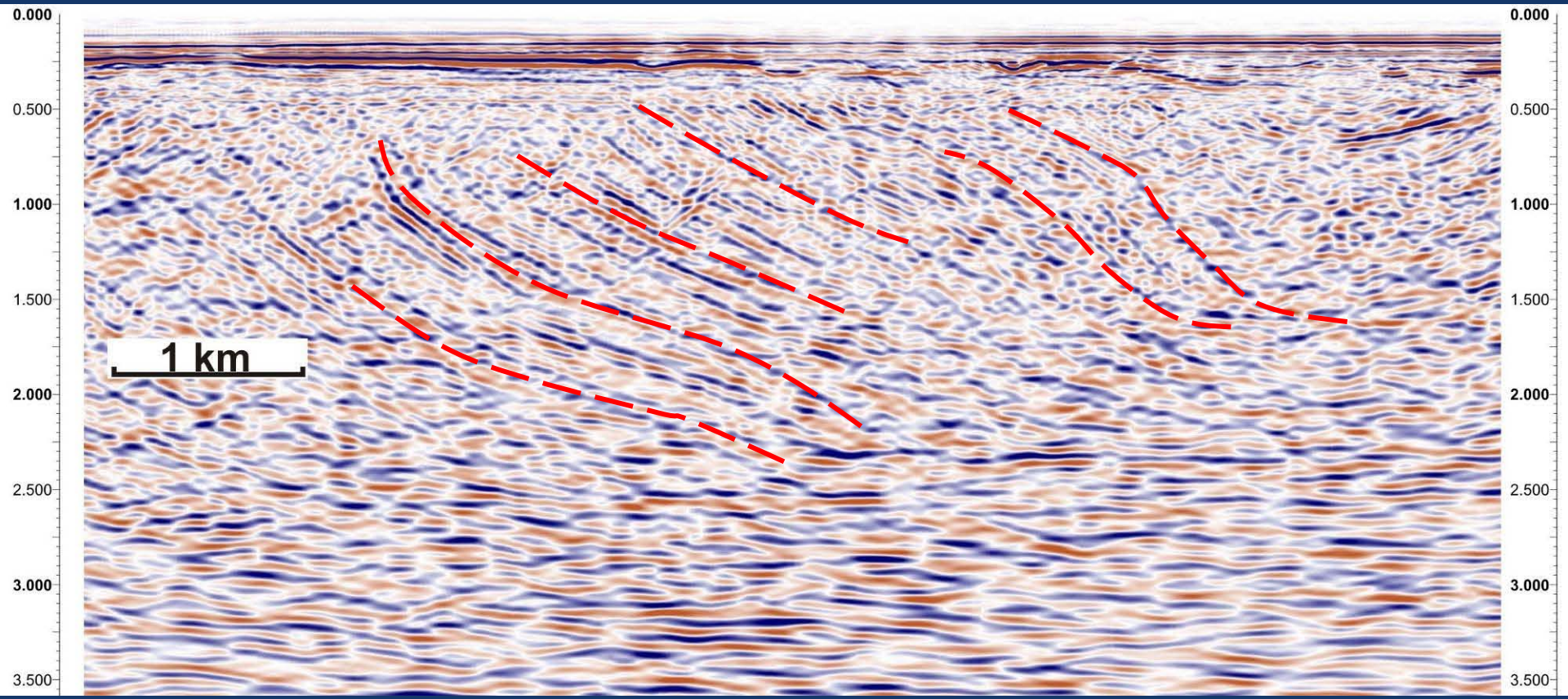
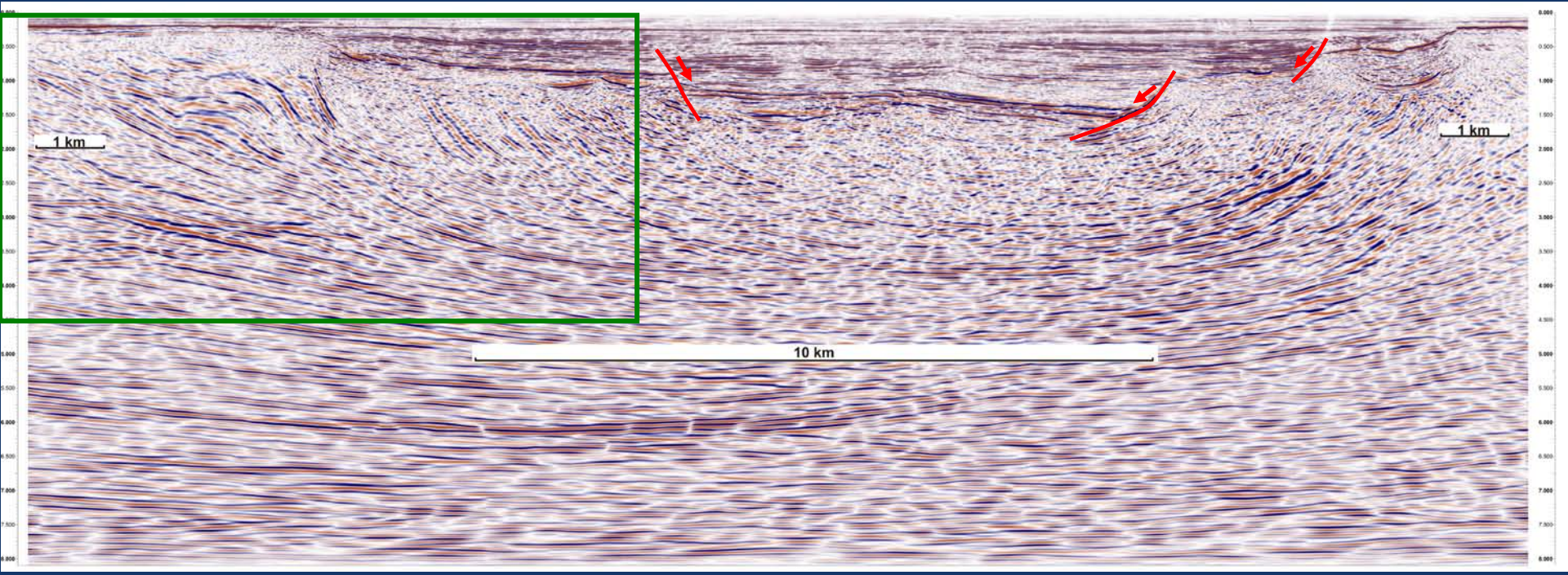
Wrangel Arch: example of south-vergent fold and thrust fault structural pattern



Wrangel Arch: example of doubble-vergent fold and thrust structural pattern and superimposed extensional features

SOUTH

NORTH



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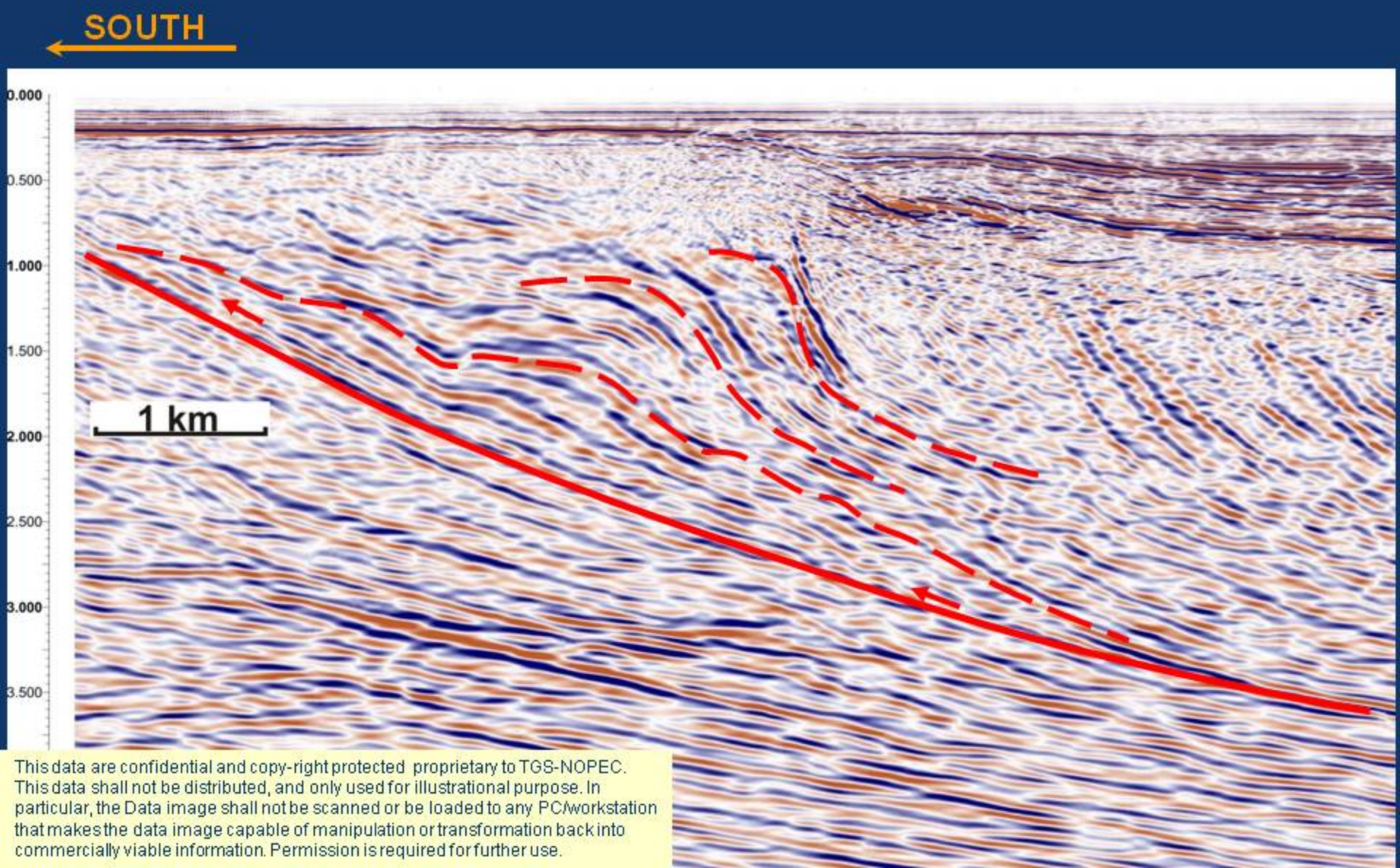
Wrangel Arch: example of south-vergent fold and thrust structural pattern



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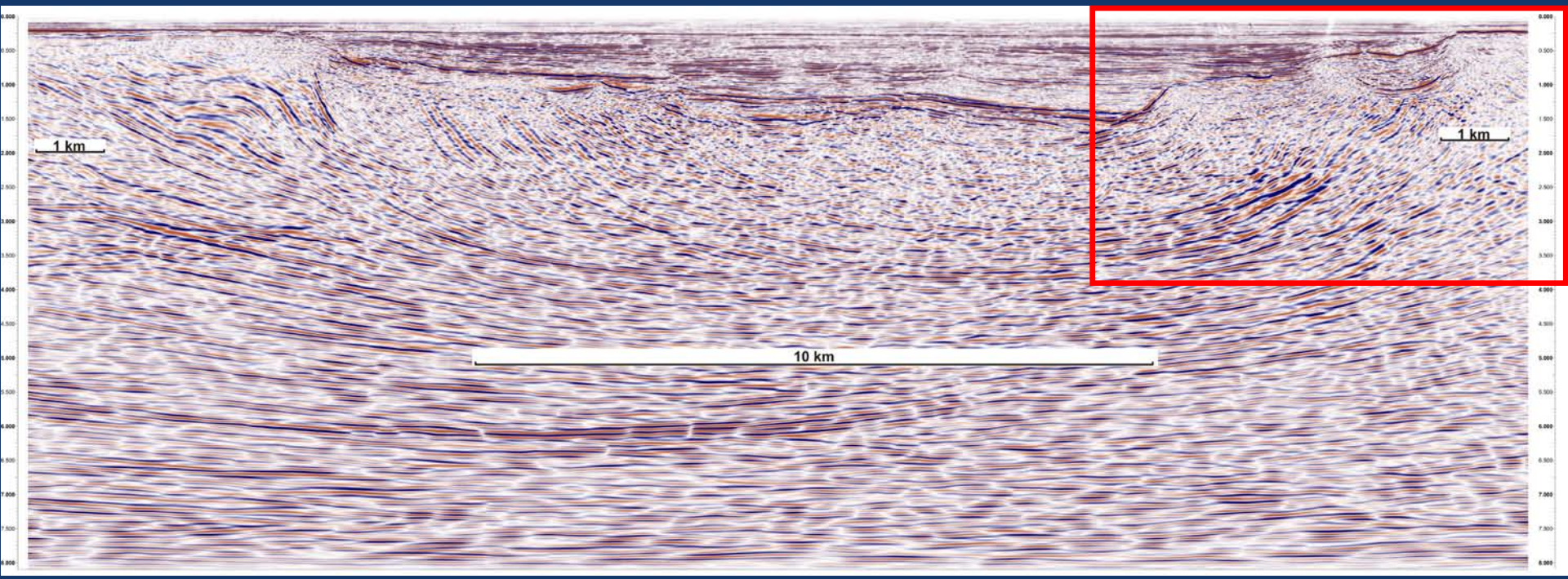
Wrangel Arch: example of doubble-vergent fold and thrust structural pattern and superimposed extensional features

SOUTH

NORTH



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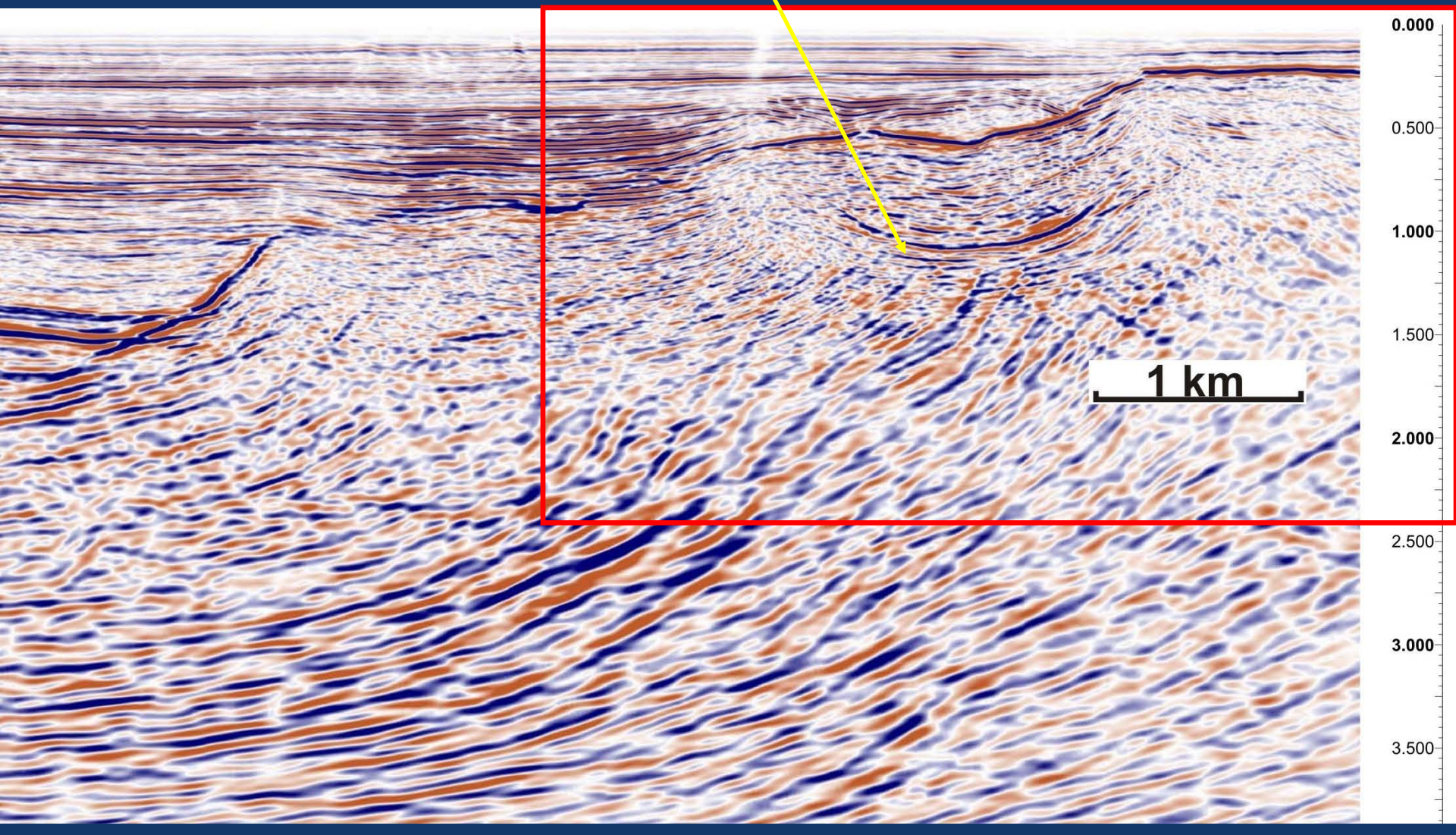
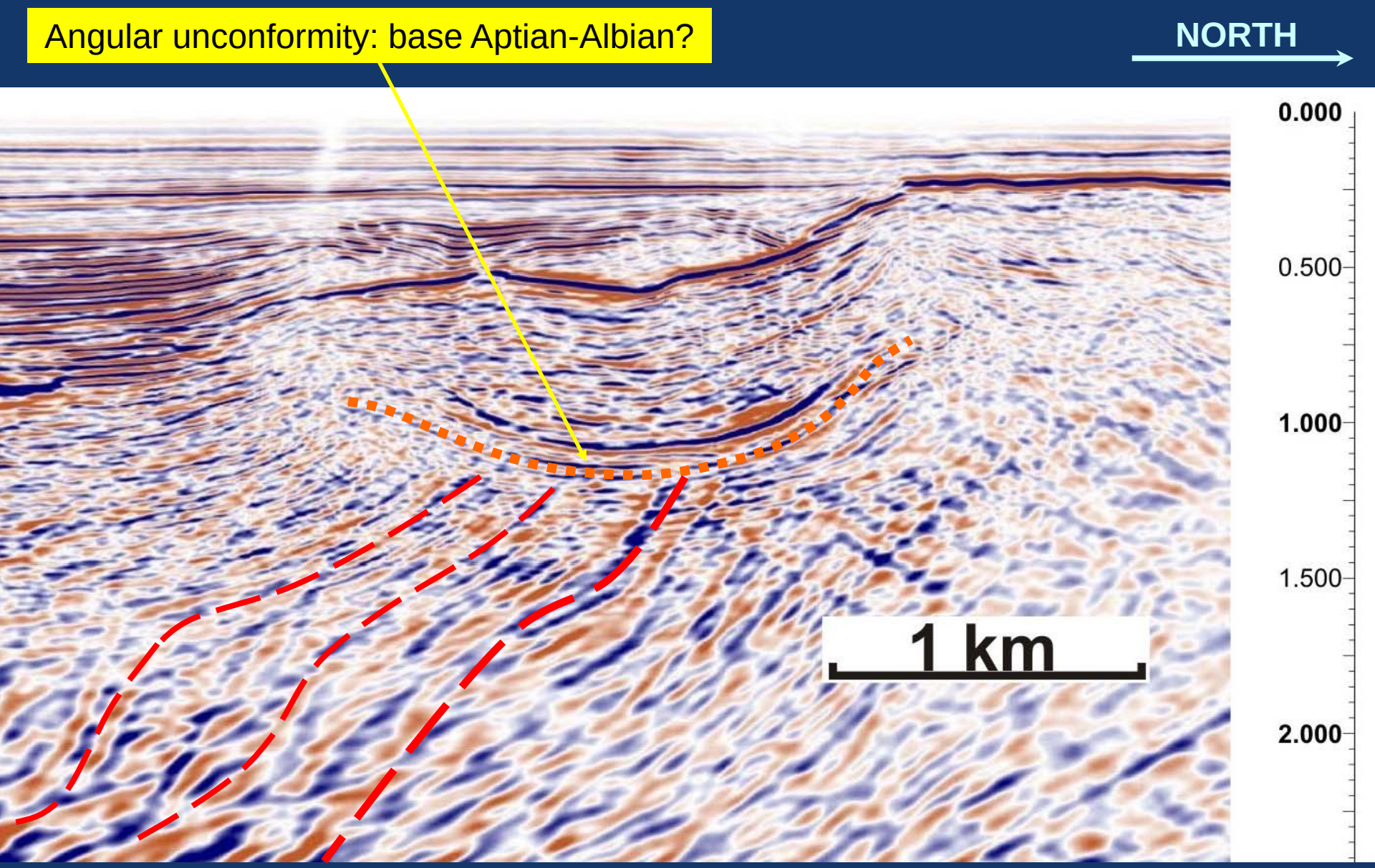
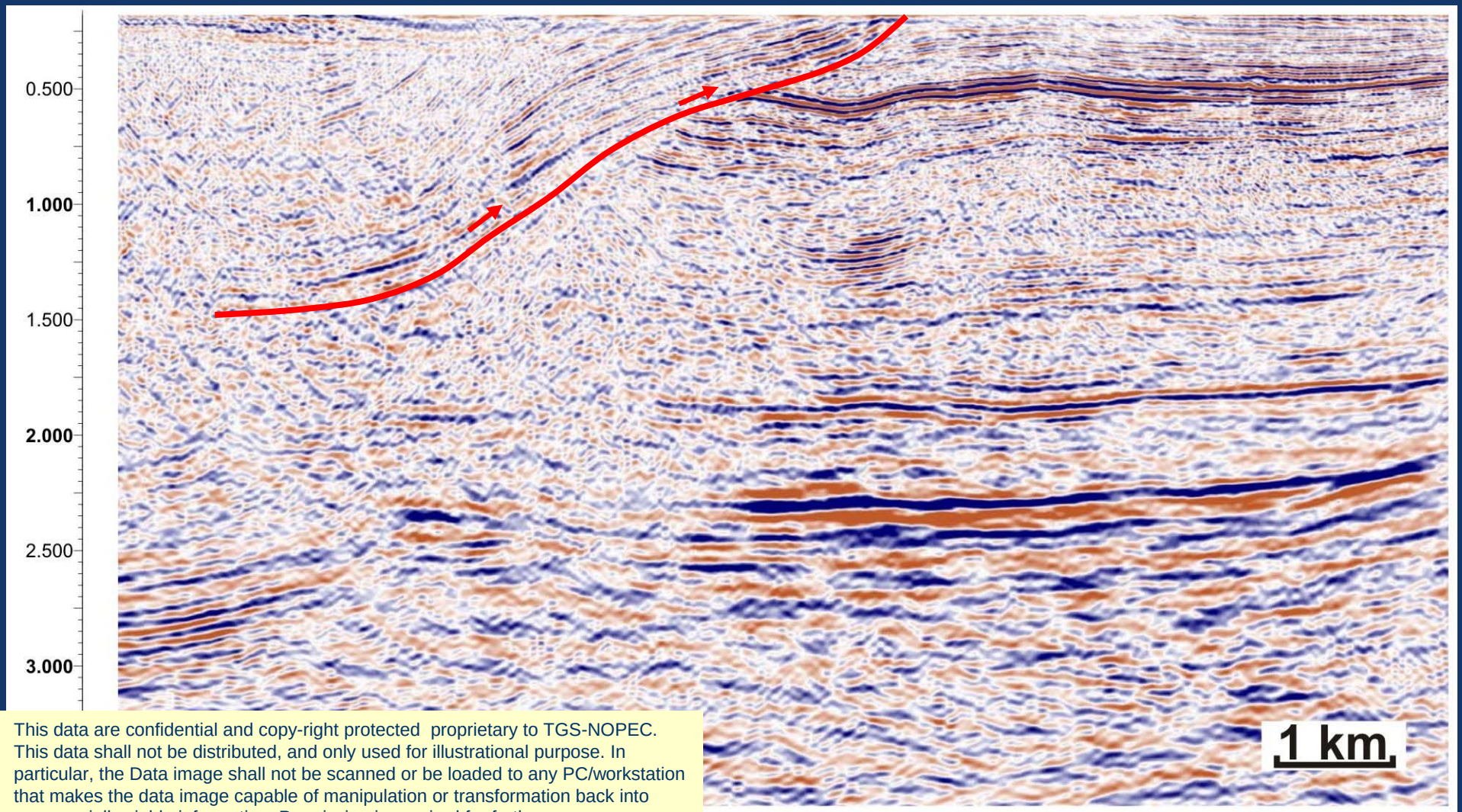
Wrangel Arch: example of north-vergent fold and thrust structural pattern



Wrangel Arch: example of north-vergent fold and thrust structural pattern



Wrangel Arch front: example of north-vergent thrust faults



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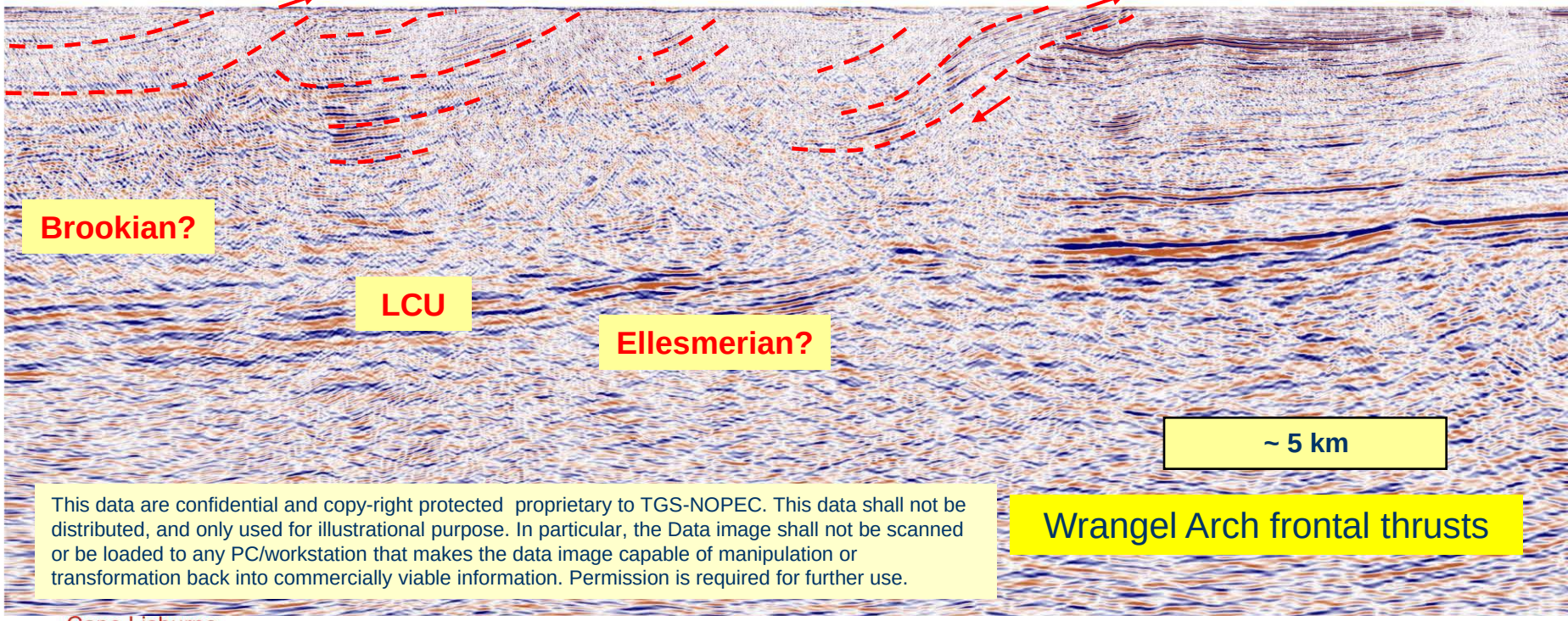

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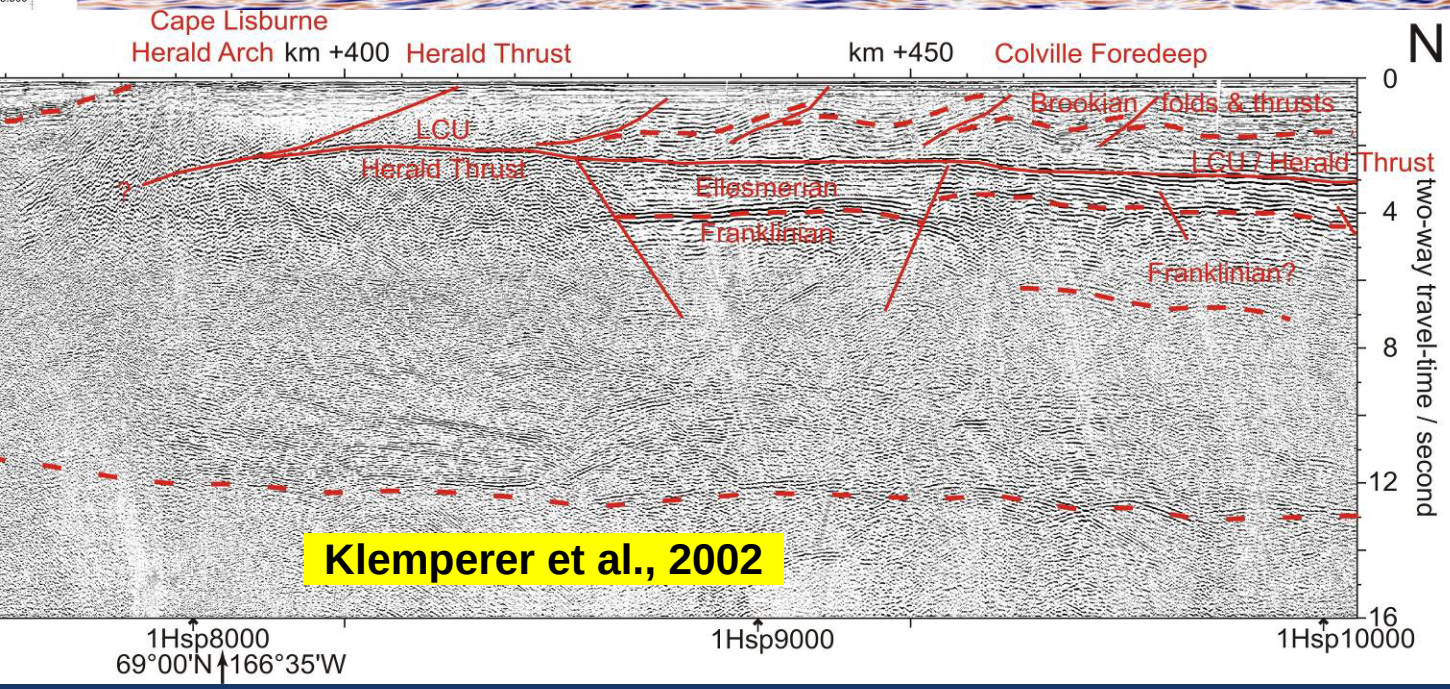

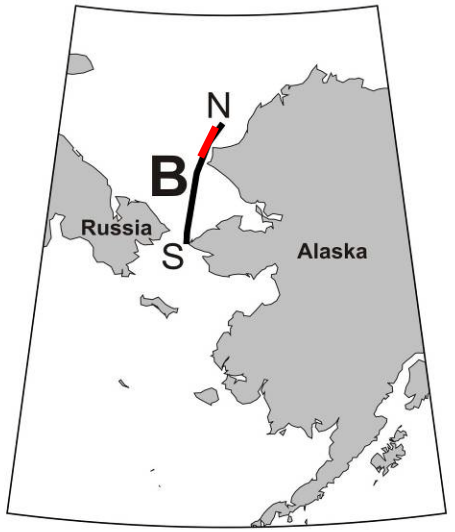

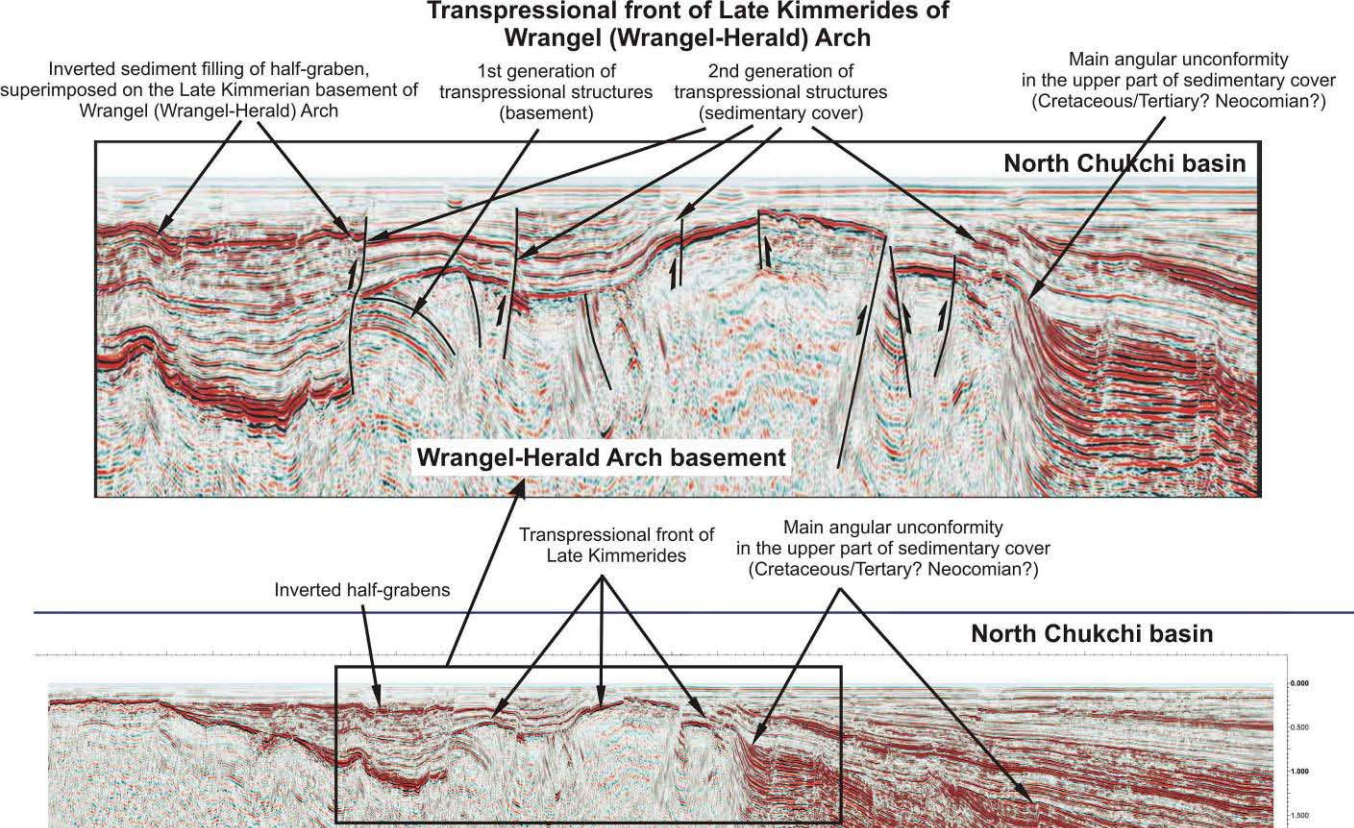

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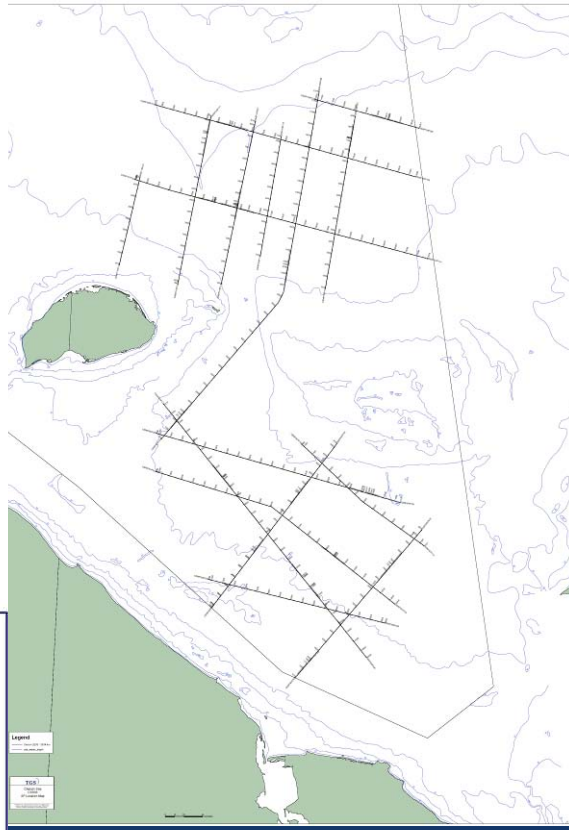


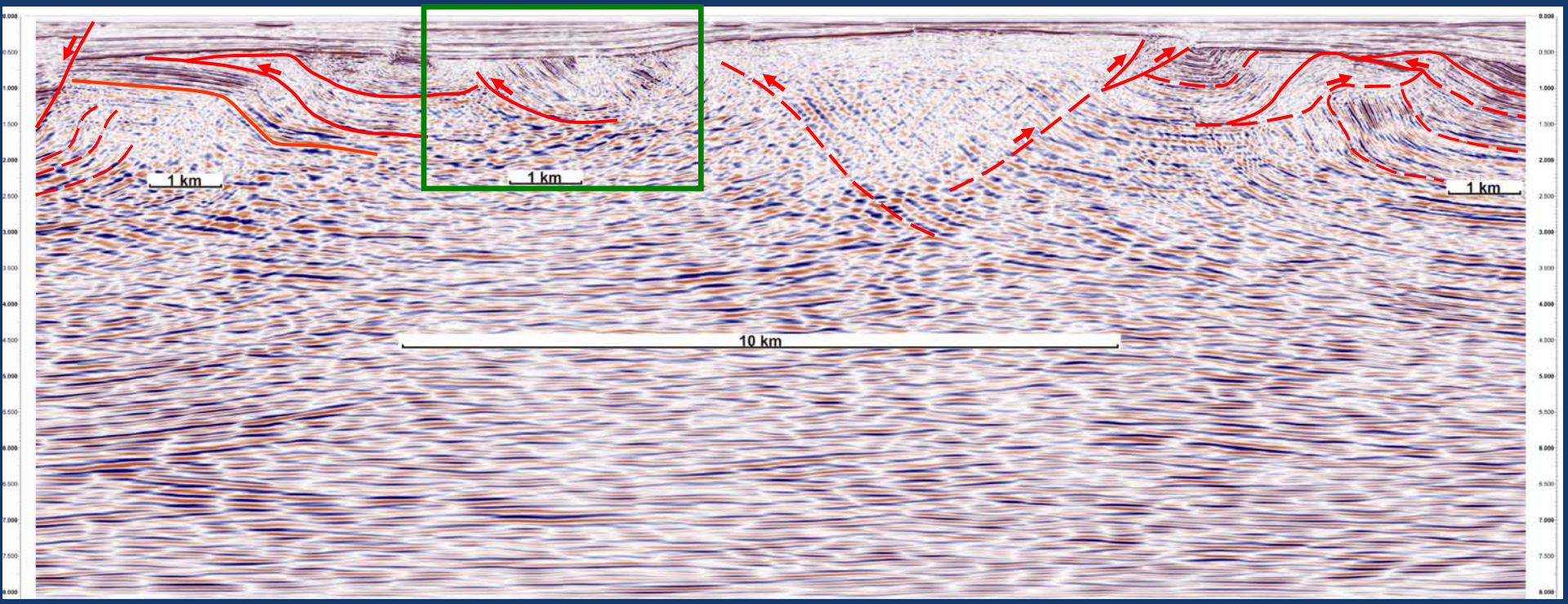
Wrangel Arch and adjacent North Chukchi sedimentary basin:

Structural pattern and stages of deformation

Albian +Mid-Brookian+Tertiary transpression events?

TGS

Wrangel Arch front: example of double-vergent / transpressional pattern



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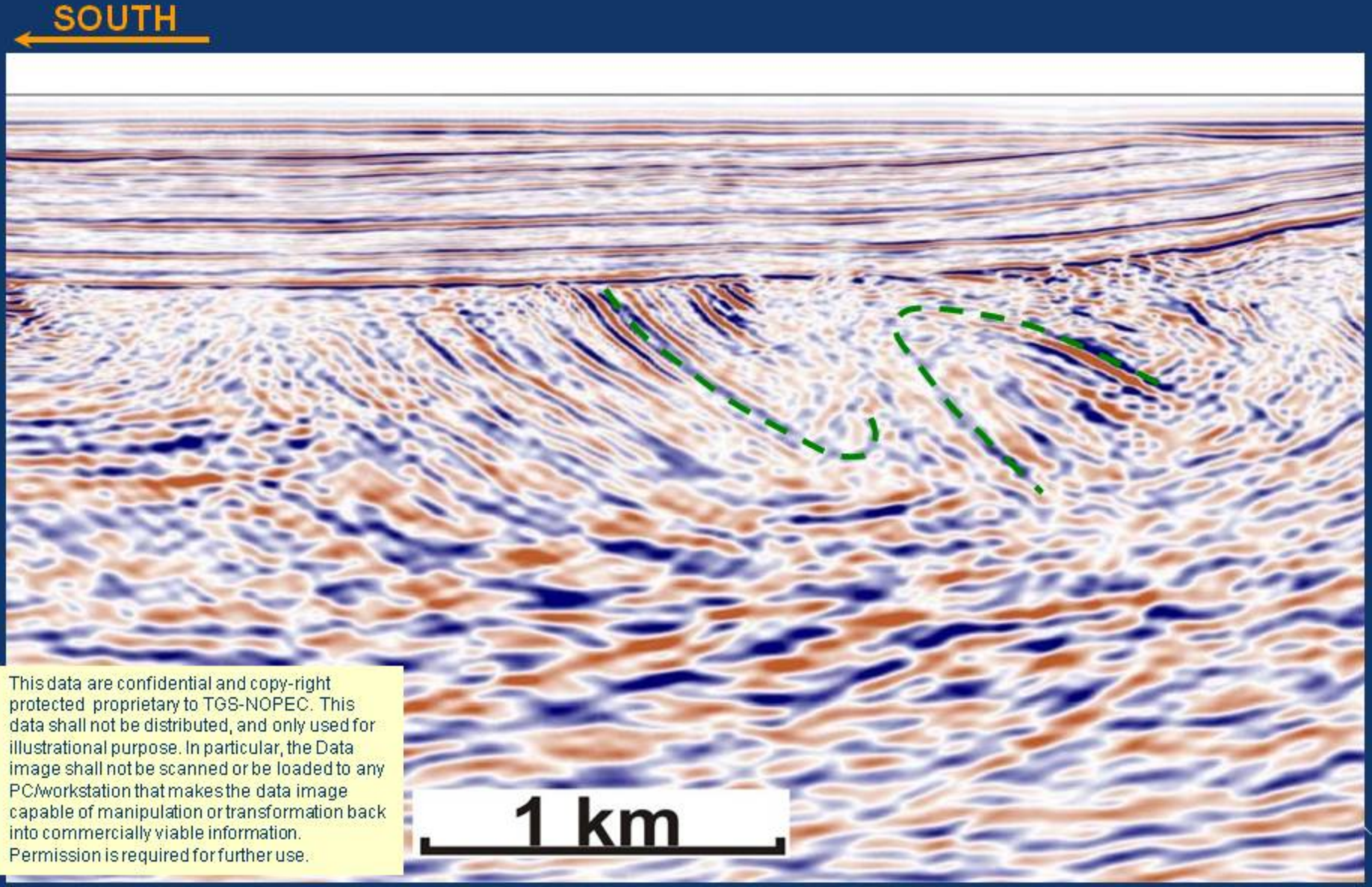
Wrangel Arch front: example of south-vergent folds



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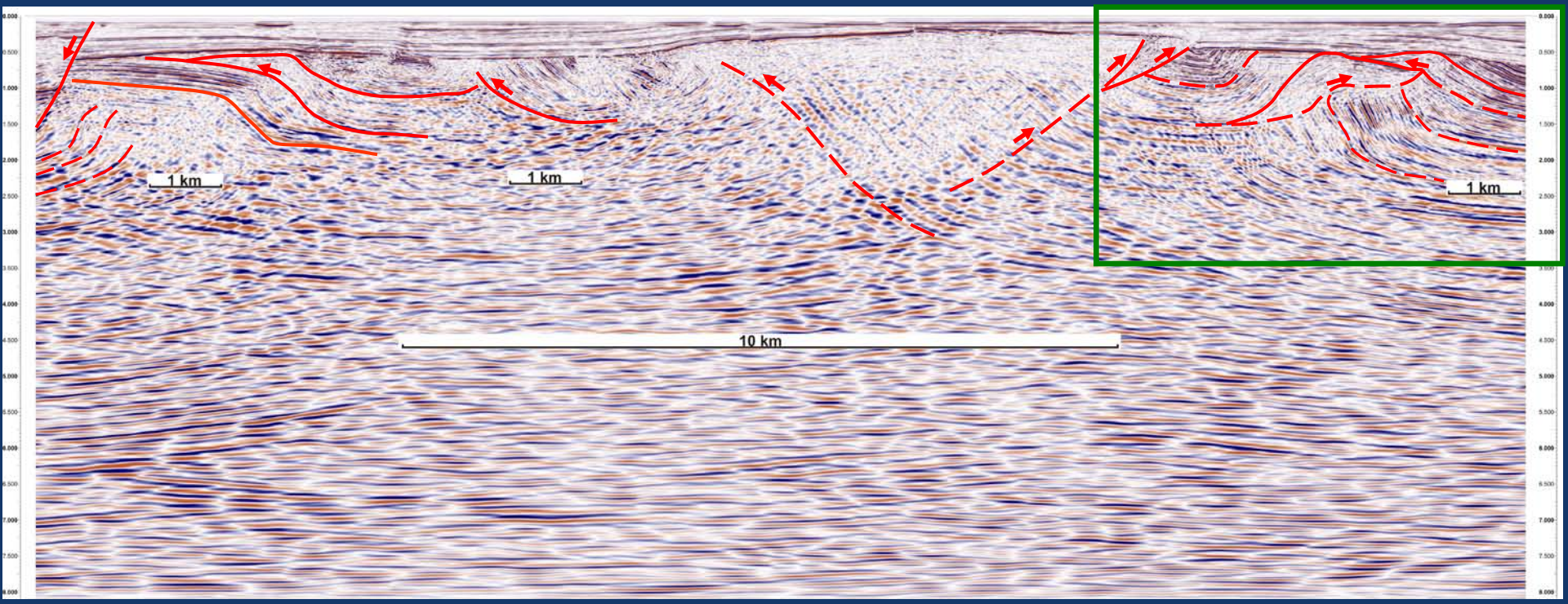
Wrangel Arch front: example of double-vergent / transpressional pattern

SOUTH

Pop-up?

NORTH



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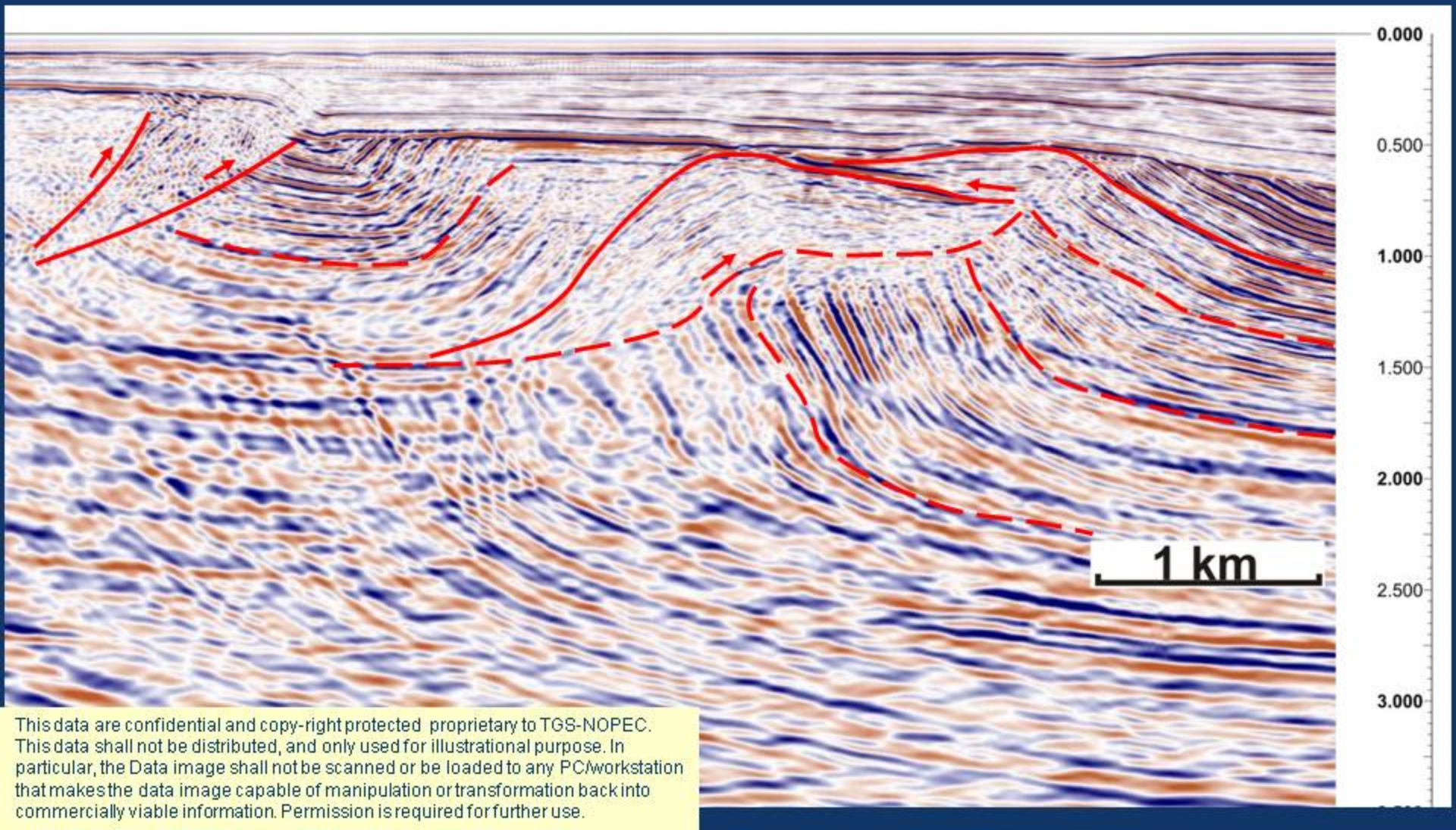
Wrangel Arch front: dominating north-vergent thrust faults



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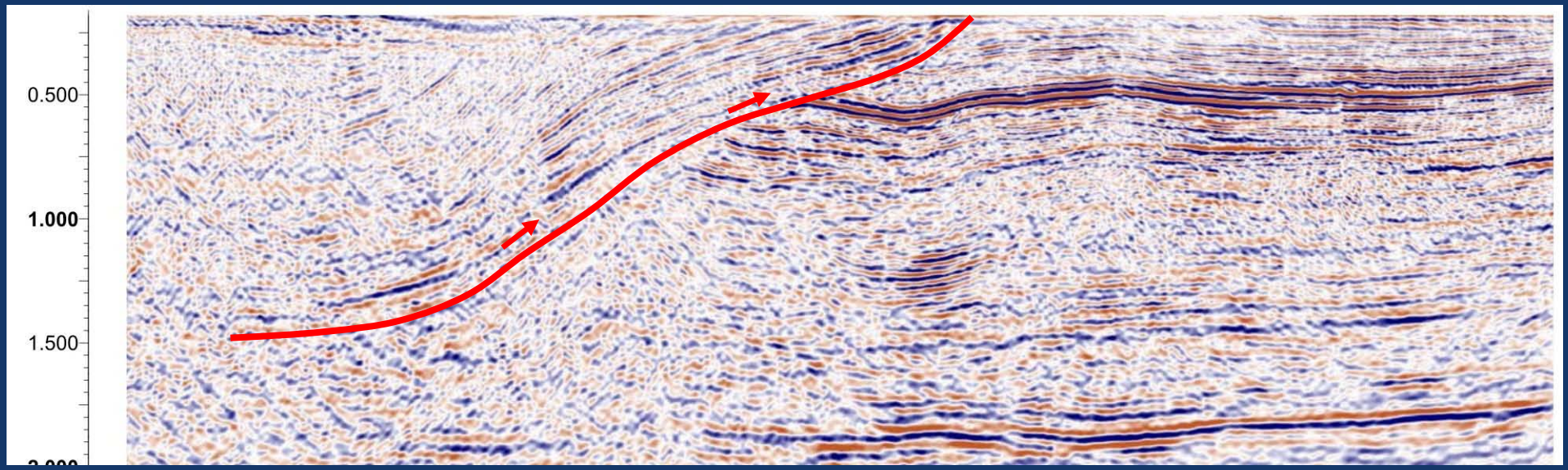
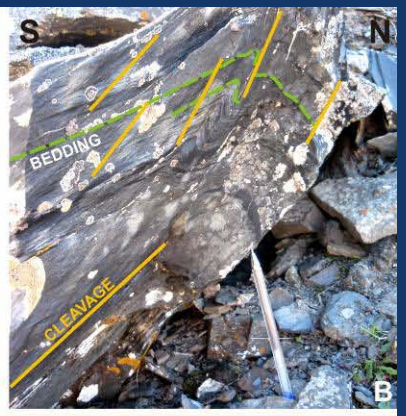
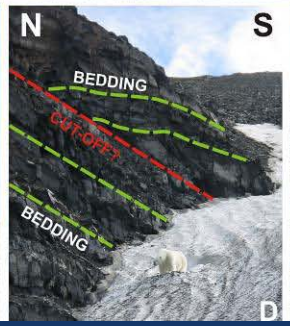
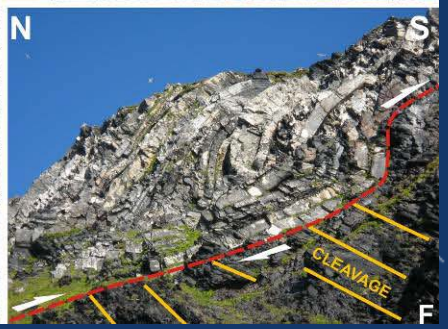
North-vergent fold and thrust structural pattern

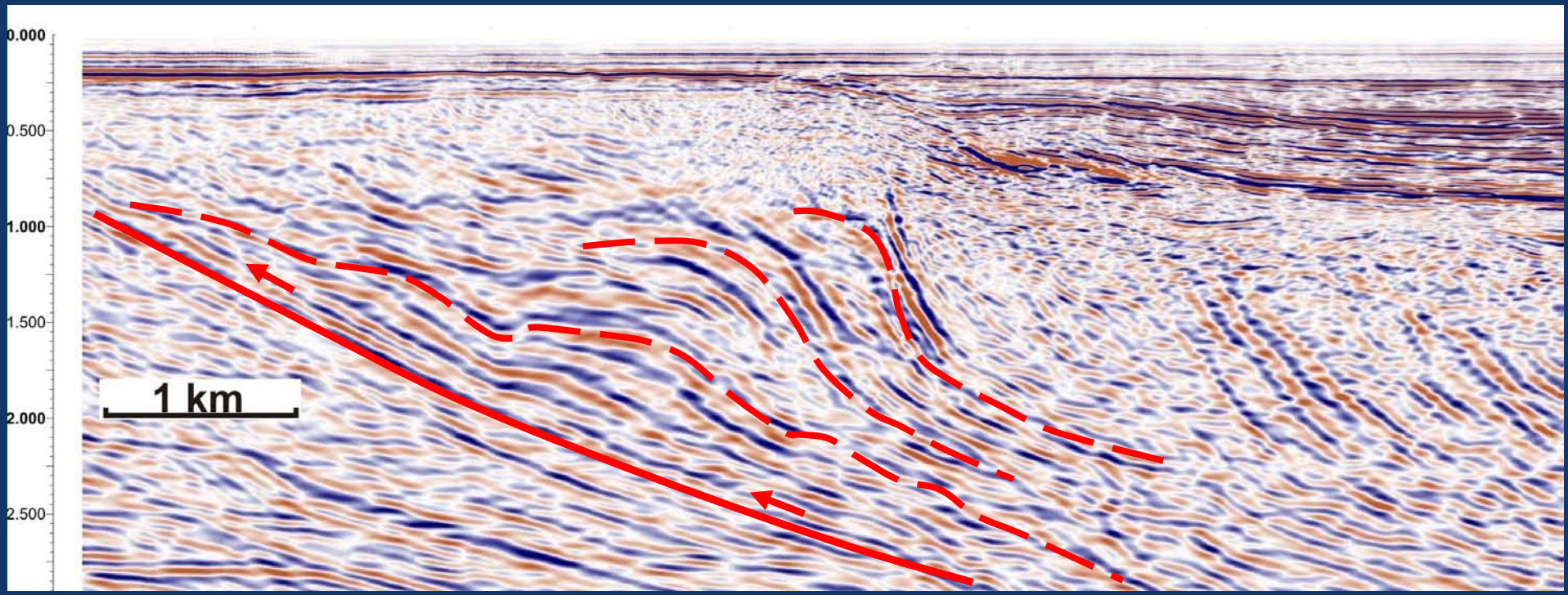




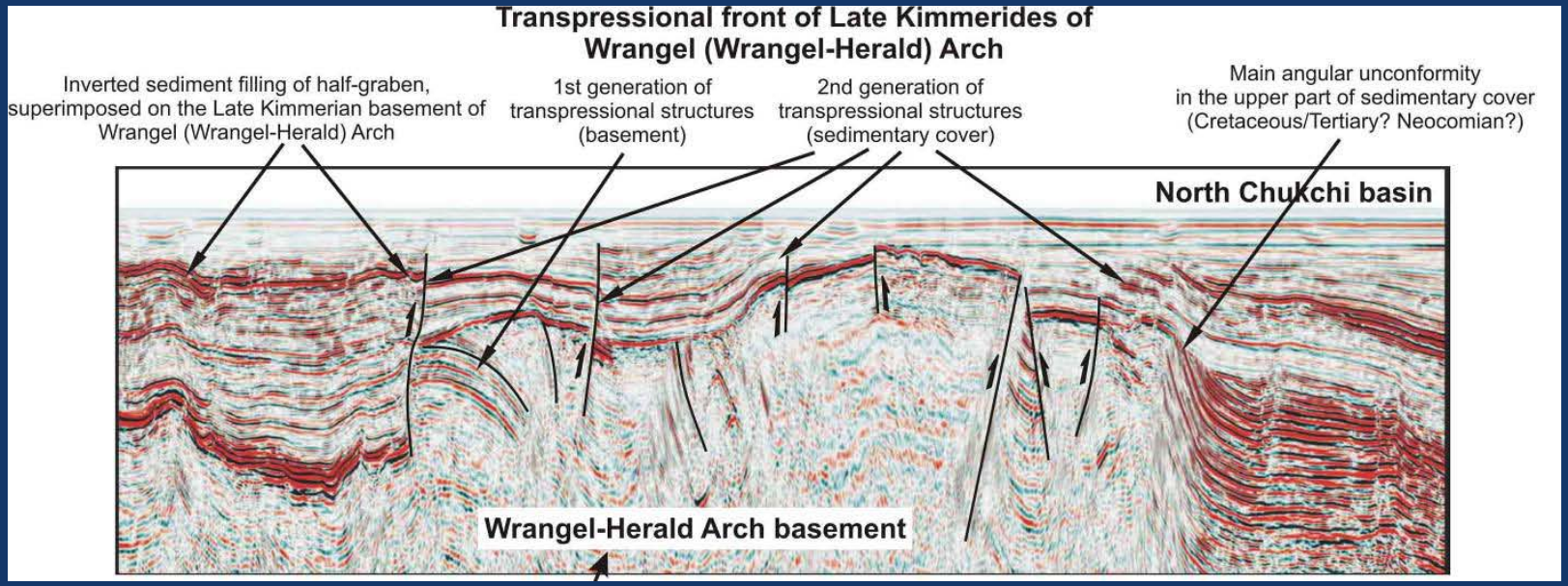




South-vergent (opposite) fold and thrust structural pattern



Transpressional tectonics

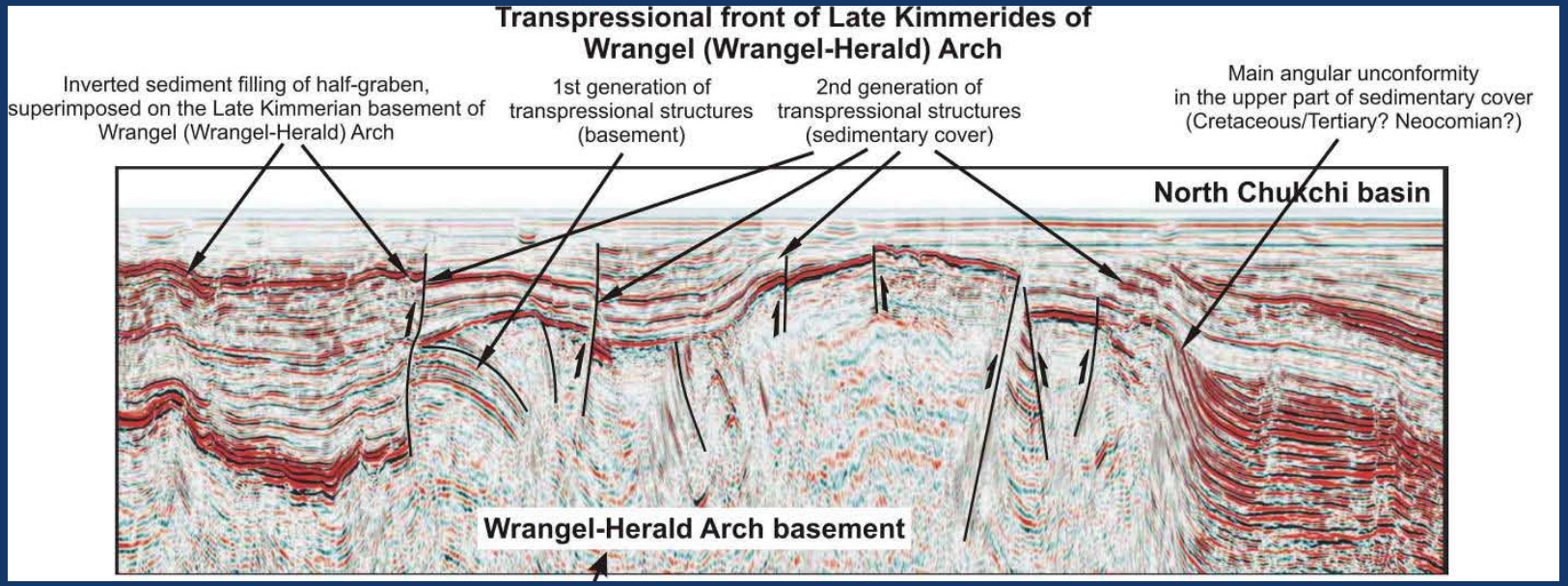


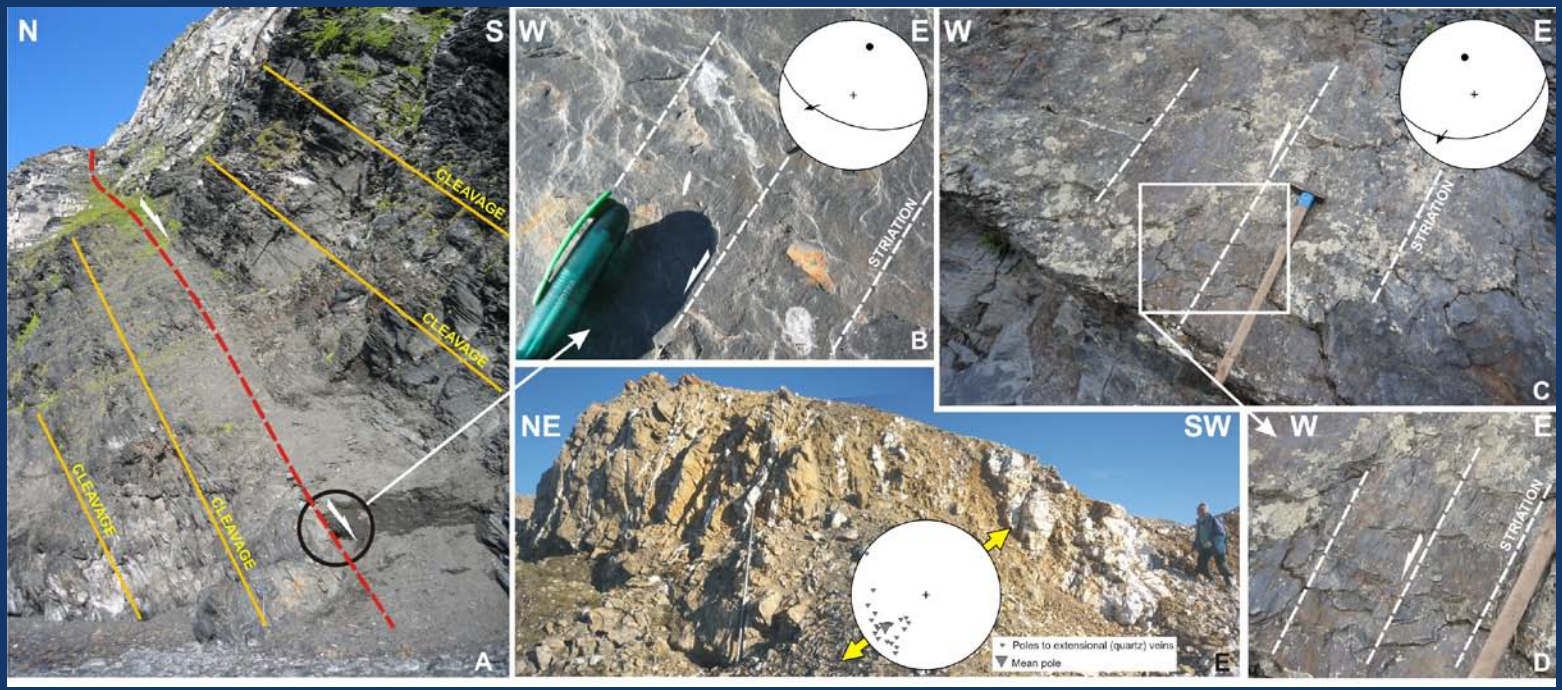
D-C_1,

Neizvestnaya river,

Z-folds with vertical exes pointing to the dextral displacements

Superimposed extensional/transtensional structures





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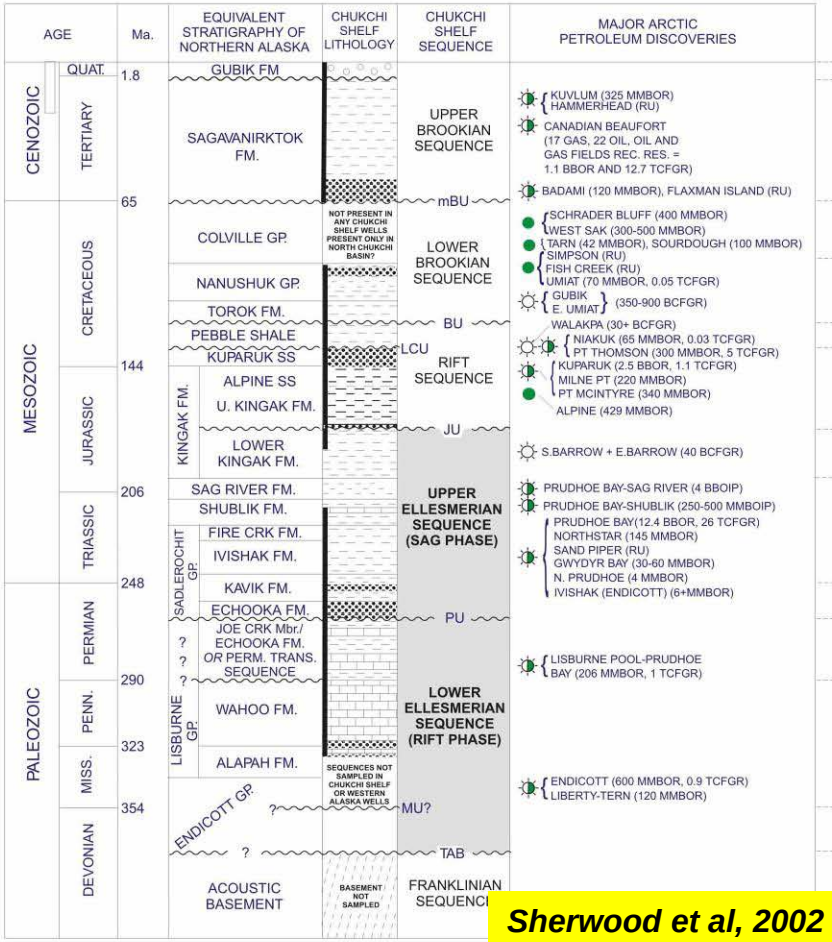
U.S. Chukchi shelf stratigraphic column



Sherwood et al, 2002

EXPLANATION

MBU: MID-BROOKIAN UNCONFORMITY
BU: BROOKIAN UNCONFORMITY
LCU: LOWER CRETACEOUS UNCONFORMITY
JU: JURASSIC UNCONFORMITY
PU: PERMIAN UNCONFORMITY
MU: MISSISSIPPIAN (?) UNCONFORMITY
TAB: TOP OF ACOUSTIC BASEMENT

SEQUENCES SAMPLED BY CHUKCHI SHELF WELLS

HANNA TROUGH FILL

SANDSTONE
CONGLOMERATE
SHALE
SILTSTONE
LIMESTONE
INFERRED METAMORPHIC/ IGNEOUS

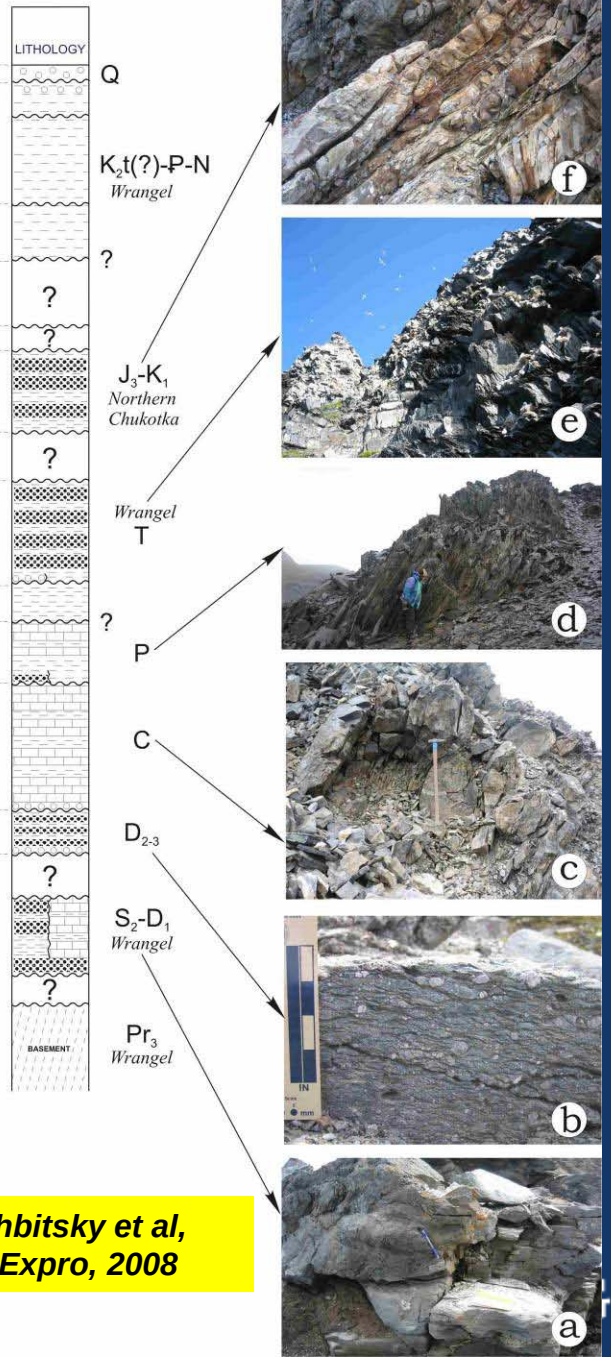
OIL FIELD (RESERVES)
GAS FIELD (RESERVES)
OIL AND GAS FIELDS (RESERVES)

MMBOR: MILLIONS OF BARRELS OF OIL, RECOVERABLE
MMBOIP: MILLIONS OF BARRELS OF OIL, IN PLACE
BBOR: BILLIONS OF BARRELS OF OIL, RECOVERABLE
BBOIP: BILLIONS OF BARRELS OF OIL, IN PLACE
BCFGR: BILLION CUBIC FEET OF GAS, RECOVERABLE
TCFGR: TRILLION CUBIC FEET OF GAS, RECOVERABLE
RU: RESERVES UNKNOWN

ABSOLUTE TIME FROM PALMER (1998); RESERVES FROM ALASKA DIVISION OF OIL AND GAS (1998) AND NEWS SOURCES AS OF DECEMBER 1999

(Sherwood et al., 2002, GSA Special Paper 360, Ch. 3)
Stratigraphic column for U.S. Chukchi shelf. Upper and Lower Ellesmerian sequences (shaded) represent the Hanna trough sedimentary fill.

Russian Northern Chukchi shelf inferred stratigraphic column



Verzhbitsky et al, GeoExpro, 2008

Thank you very much for your attention!

Thank You!

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vladimir.verzhbitsky@tgsnopec.com

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