[PS]Seismic Fault Mechanical Stratigraphy of a Complex Impact Structure, Chukchi Sea, Offshore Alaska*

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Abstract

Complex impact structures are often misinterpreted in seismic sections as tectonic structures (e.g.: wrench faults, reactive diapirs, volcanism, etc.). Using Seismic Fault Mechanical Stratigraphy (SFMS), we propose a methodology for the differentiation of complex impact structures from tectonic structures. The case study is conducted on 2D seismic lines in the Chukchi Sea, offshore Alaska.

SFMS is a method used to analyze the geological ages of the faults in seismic sections. The rationale behind this method consists of two premises: Steno's law of superposition and cross-cutting relationships and the deterministic and empirical description of the bulk modulus as affected by increasing sediment depth and age. From these principles, it can be said that most deep-seated faults propagate from the bottom to the top and thus the youngest strata that a fault cuts indicates the most recent age at which a fault has been active. Additionally, the proper delineation of fault timing is critical to the assessment of petroleum system migration dynamics. For this feature, the fault mechanical stratigraphy identifies four fault generations and clearly shows that the faults related to the structure can be isolated to the Middle Eocene.

Within seismic resolution two structural features of complex impact structures are identified: a central uplift in the crater floor produced by rebound, and gravity-collapsed terraced faults rimming the crater. These structural features are generated within minutes, a time range drastically shorter than that required for tectonic structures (i.e. ka to ma). The tightly constrained timing and short duration of these associated concentric faults defined by SFMS strongly suggest this Chukchi Sea structure to be a complex impact structure.

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1. Introduction:

During the decade of the 80's and early 90's more than 1200 seismic lines were acquired on the Chukchi Sea offshore Alaska (Figure1 and 2) for hydrocarbon exploration purposes. In an area located at 71° N and 165° S 5 seismic lines image an structure with characteristic features of a complex meteorite impact crater (Ruiz Lozano, 2017) (Figure 3).

Asides from the morphology of impact structures, the analysis of the ages, and the fault trace characteristics, of the faults associated with complex impact craters, are crucial in order to distinguish impact structures from structures caused by endogenic processes (e.g. diapirs).

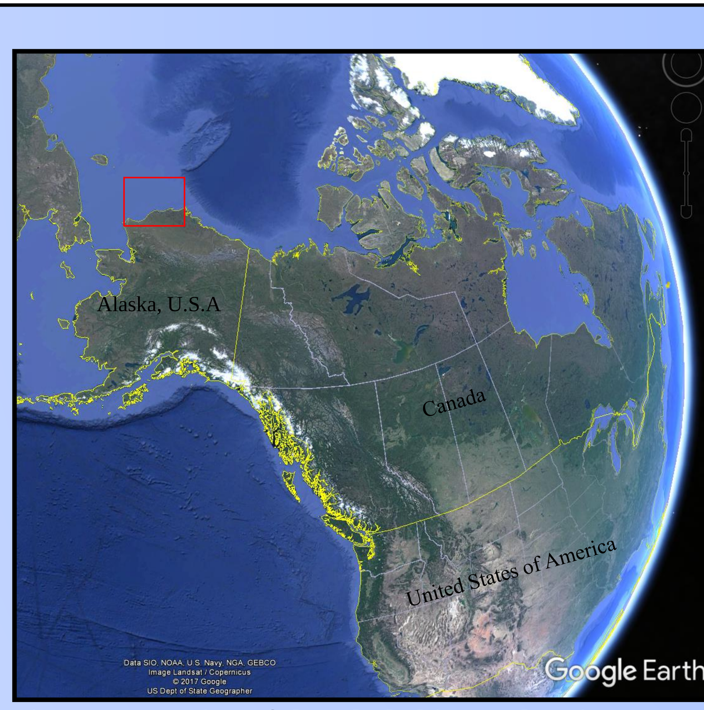

Figure 1 Location of the Chukchi Sea Planning area

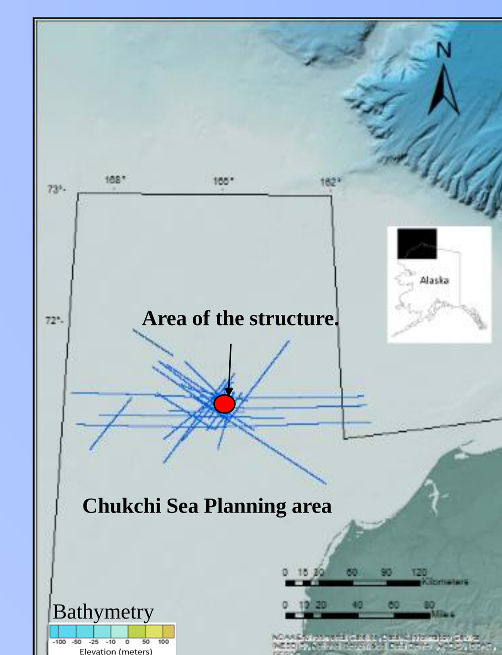

Figure 2 Impact structure and survey lines.

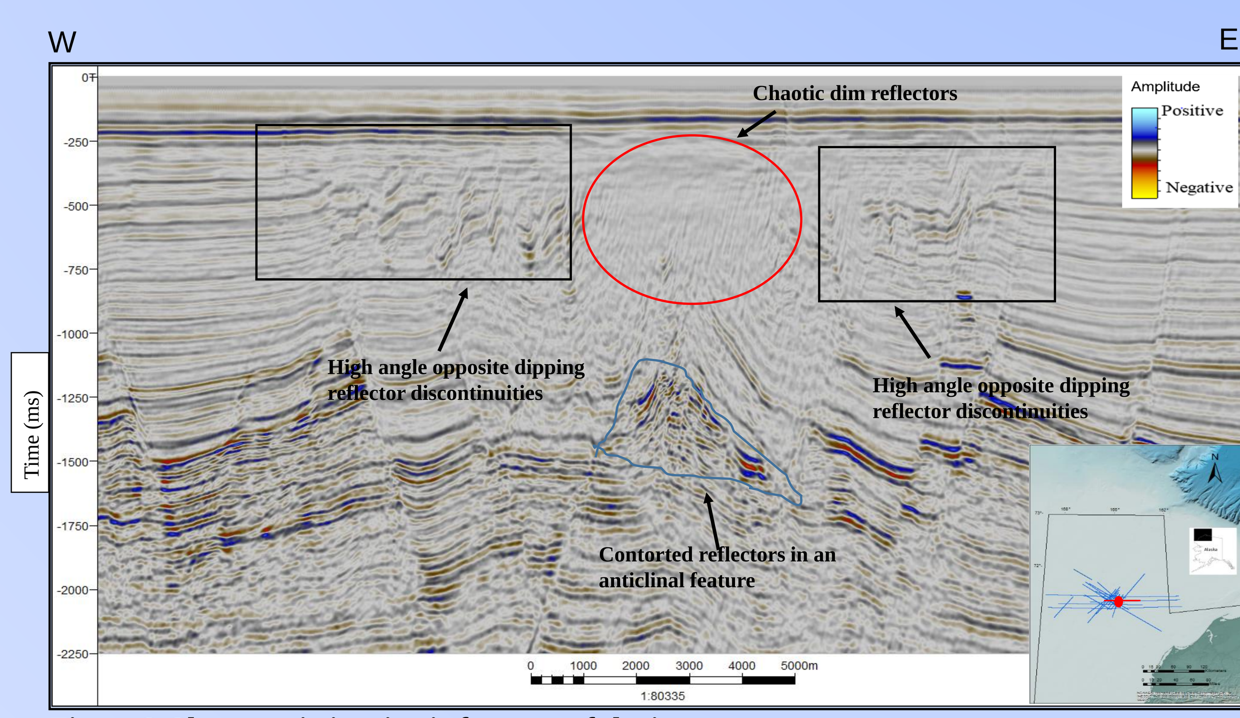

Figure 3 Characteristic seismic features of the impact structure

2. Geological Background:

Thurston and Theiss 1987 recognized six tectonic provinces in the Chukchi Sea (Figure 4), these provinces are the result of rifting events during the late Devonian and early Permian, and transtensional stresses during the Tertiary.

The area of the crater is located in the Northcentral subbasin, a subdivision of the Central Chukchi Basin. This subbasin is the result of transtentional stresses during the Tertiary,

Five seismic stratigraphic operational sequences are recognized in this area (Figure 5 and 6); the facies vary slightly in the whole Central Chukchi Basin, except at the area of the crater (Figure 5). Where chaotic and contorted facies can be recognized, contrasting with the typical parallel/subparallel facies on the area.

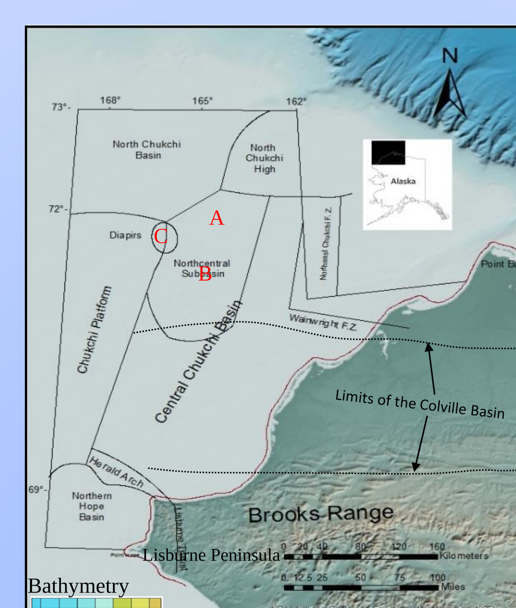

Figure 4 Major tectonic provinces of the Chukchi Sea planning area

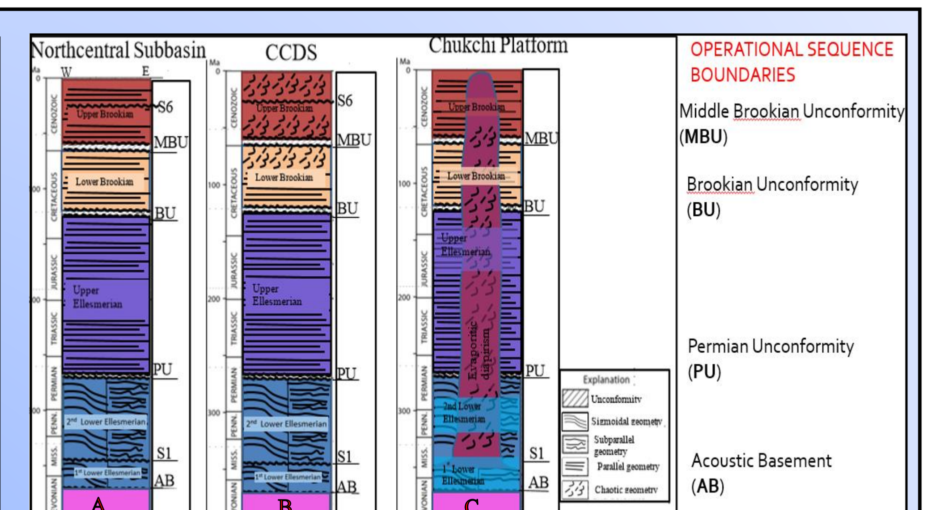

Figure 5 Seismic stratigraphic section of: A) Northcentral subbasin, B) Impact structure area, and C) Chukchi Platform (diapirs).

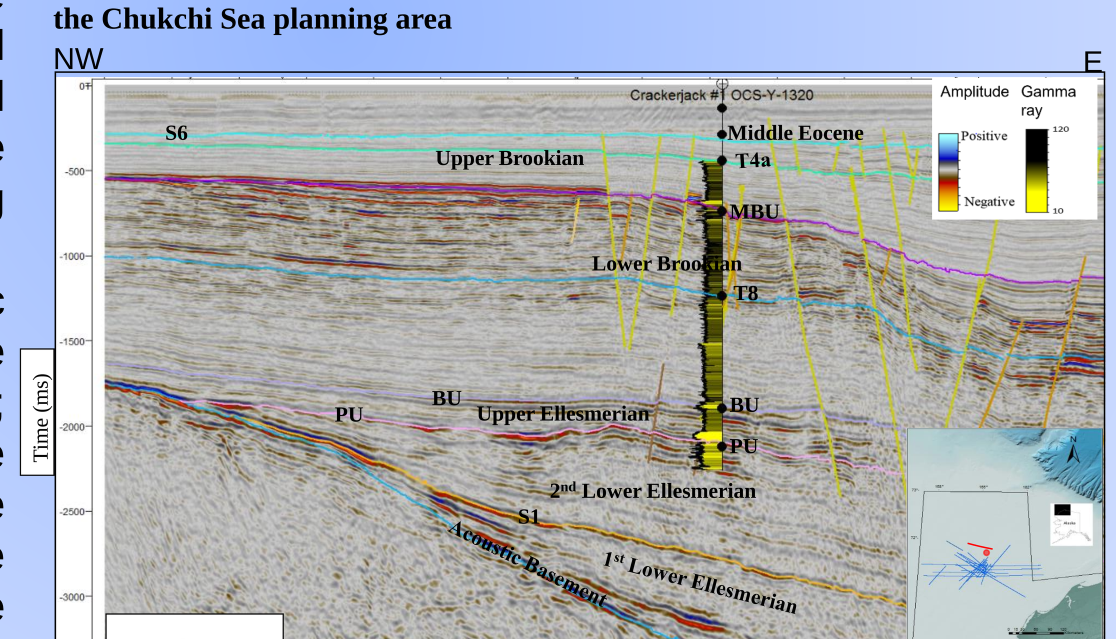

Figure 6 Seismic stratigraphic well-tie on line ch90-001b

3. Fault Interpretation:

The faults in the area of interest must be properly interpreted in order to avoid correlation mistakes during the interpretation of operational sequence boundaries. Besides, the faults provide an insight on the tectonism of the basin.

For seismic fault mechanical stratigraphy (SFMS) it is very important to interpret the fault all along its trace, the top and the bottom of the fault are key in SFMS. Attribute assisted interpretation of the faults is therefore crucial; variance reveals the extent of the fault and provides information of the definition of the trace, i.e. whether if the fault trace is narrow and well defined (Figures 7 and 8), or like in the case of the faults related with the impact structure (Figures 10, 11) wide and diffuse.

Tracing the faults from line to line; based on both the features of the structures associated with the faults, and the features of the fault itself (gauge, fault definition, fault extent) allows for an interpretation of the pseudo 3-D geometry of the fault. It can be observed that the linear geometry of the faults associated with extensional and transtensional events in the basin (Figure 11) are considerable different from the concentric geometry of the faults associated with the impact structure (Figure 12). The tectonic stress regime of the faults in the area has a sigma3 predominantly W-E trending (Figure 11), as for the sigma3 of the crater faults is concentric and radial (Figure 12).

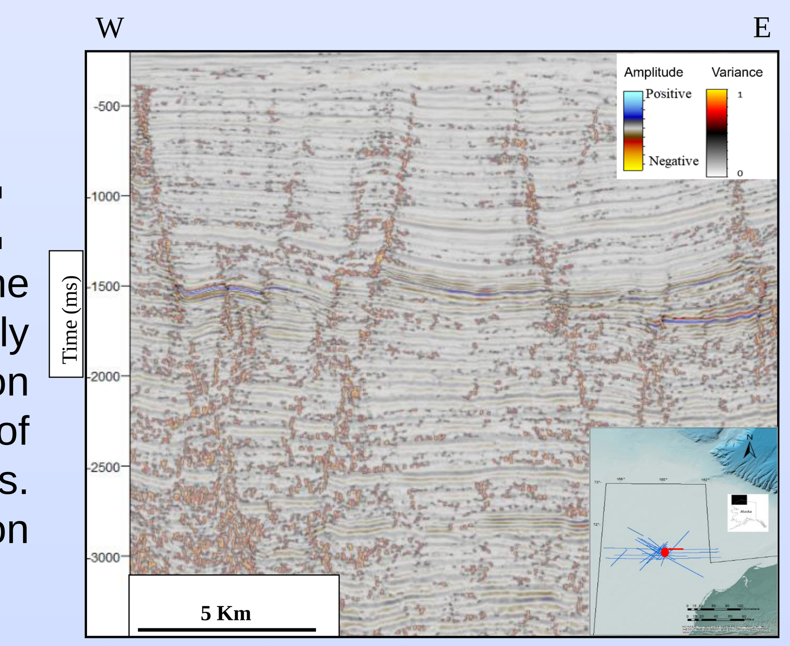

Figure 7 Uninterpreted Horst structure. Original amplitude co-rendered with variance at 70% transparency.

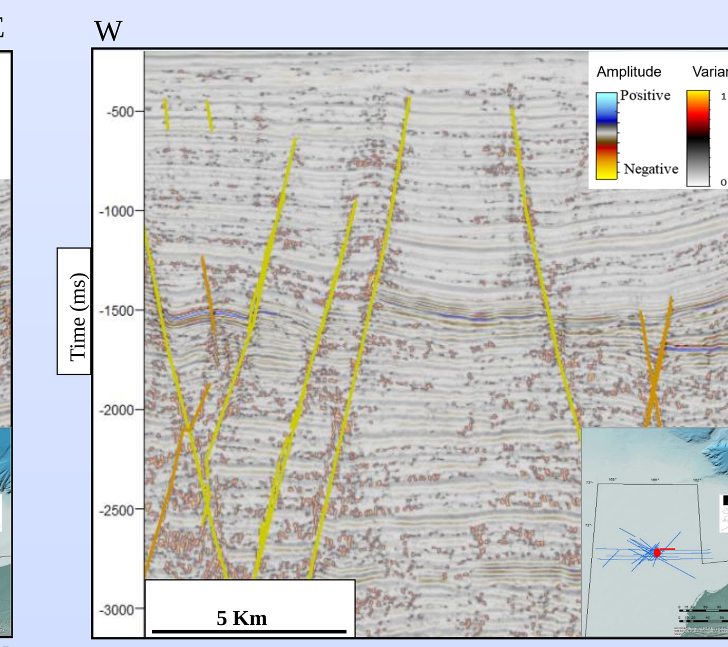

Figure 8 Horst structure. Original amplitude co-rendered with variance at 70% transparency.

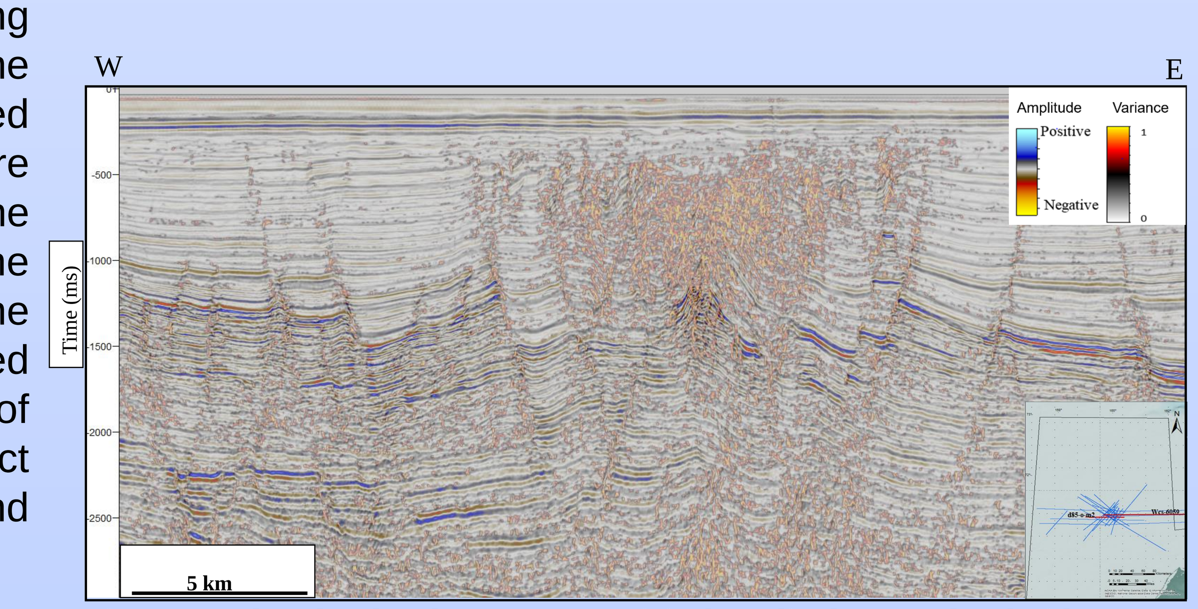

Figure 9 Faults related to the structure. Original amplitude co-rendered with variance at 70% transparency.

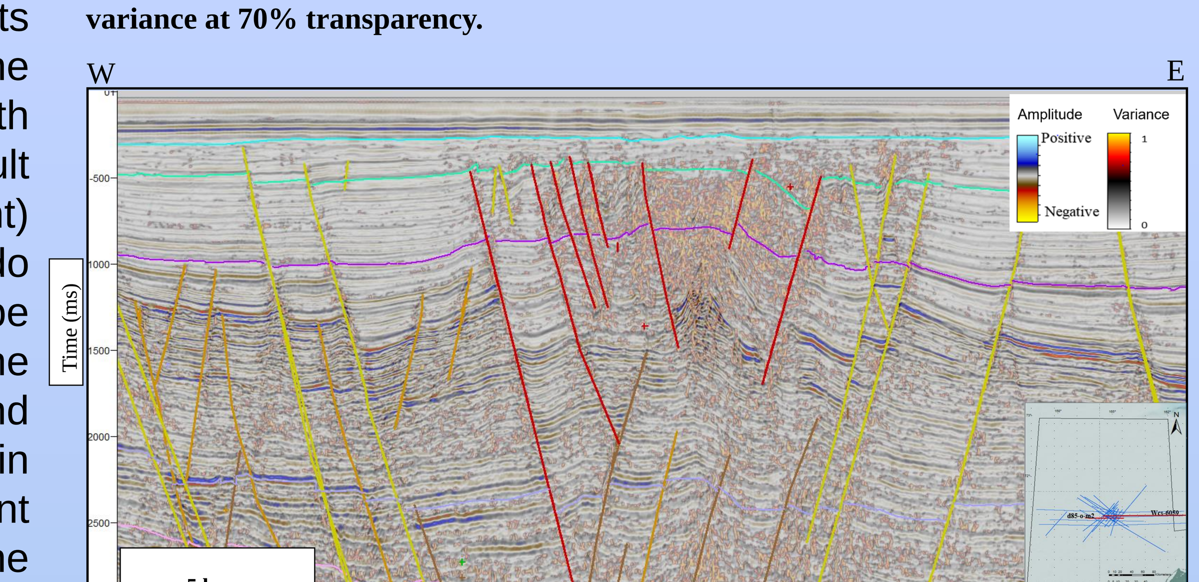

Figure 10 Faults related to the structure, interpretation. Original amplitude co-rendered with variance at 70% transparency.

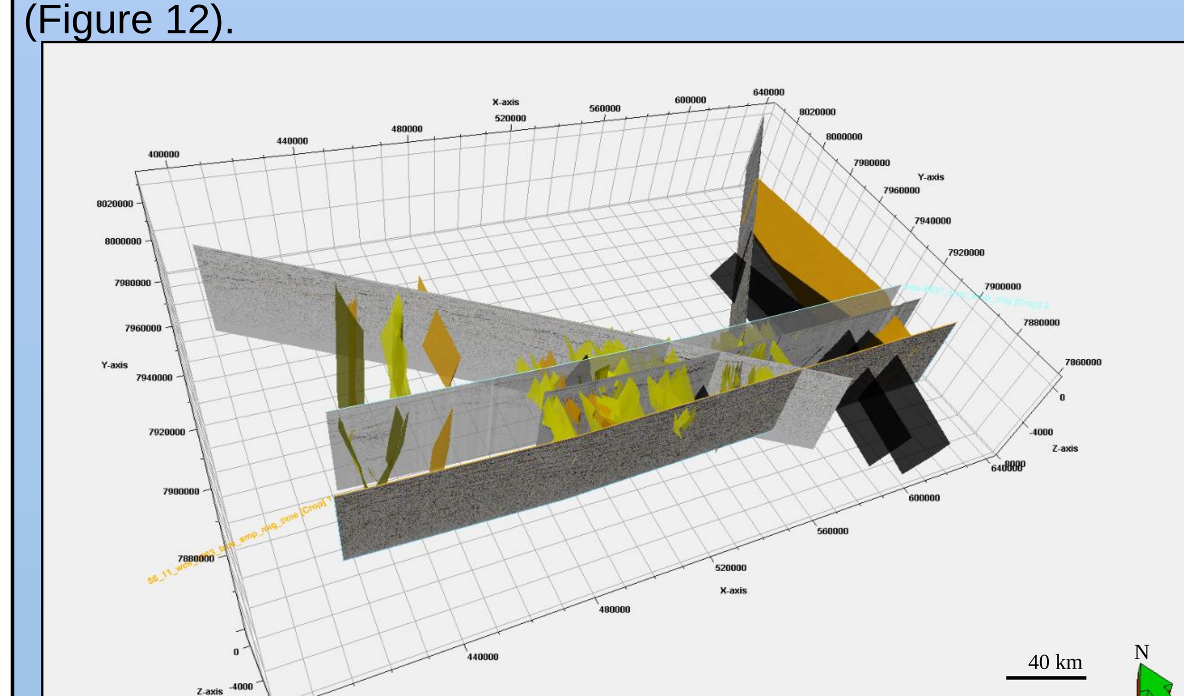

Figure 11 Pseudo 3-D geometry of faulting. Note the general W-E sigma 3 trend.

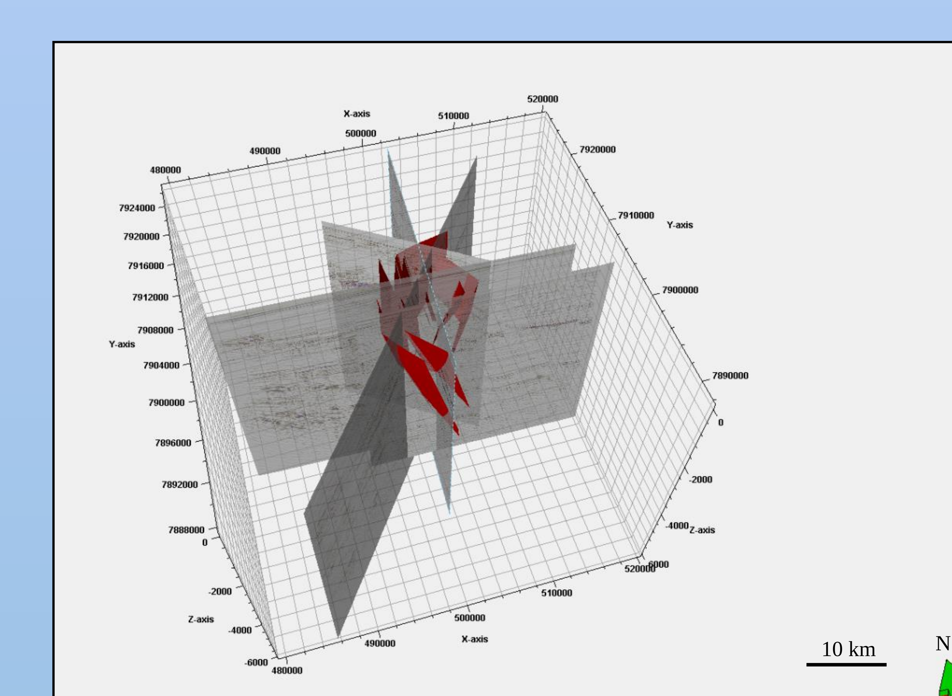

Figure 12 Pseudo 3-D geometry the faults related to the structure. Note the radial and concentric sigma3 trend.

4. Seismic Fault Mechanical Stratigraphy:

Relative ages are assigned to the faults by following Steno's law of superposition and cross-cutting relations; and the geomechanical principle that states that older rocks tend to be stronger and less prone to brittle deformation (Pigott and Abouelresh, 2016). Therefore the youngest strata affected by deep-seated faults represent the age of the fault.

Since pressure *P* is equivalent to normal stress (Pigott and Abouelresh, 2016) and since:

$$K = \frac{\sigma}{\delta V/_V}$$

then

$$K = \frac{-P}{\delta V/_V} = \frac{-P}{Ev}$$

where σ is normal stress, *K* is the bulk modulus, *V* is volume, *P* is the pressure, and *Ev* is the volumetric strain; this equation describes the increase of the bulk modulus with the increase of pressure (i.e. confining depth and geological age).

Young's modulus (E) and the Poisson's ratio (ν) in a homogenous isotropic solid are related by:

$$K(z) = \frac{E(z)}{3(1-2\nu(z))}$$

where in this case *ν* is a fixed parameter for the rock and *E* increases with increasing burial depth (age). As *E* increases so does *K*.

SFMS analysis is conducted after a proper interpretation of the operational sequence boundaries. These reflectors can be correlated to a geological age after integrating and correlating the well control information. Thus the age of these time-significant reflectors is an indicator of the approximate age and time range in which the fault that crosses it was active, therefore faults can be grouped by its age if they cross a determined time-significant reflector, and stay within a determined vertical range.

The faults related to the impact structure stop at the same stratigraphic level (Figures 13, and 14), and are as well constrained to a very limited vertical range (Figures 15, 16, 17, and 18). Which is typical of the "instantaneous" faulting of cratering events (Melosh, 1989); unlike the faults associated with endogenic structures adjacent to the crater (e.g. horsts, wrench faults), where the vertical range (i.e. geological age) varies within the same chronological family.

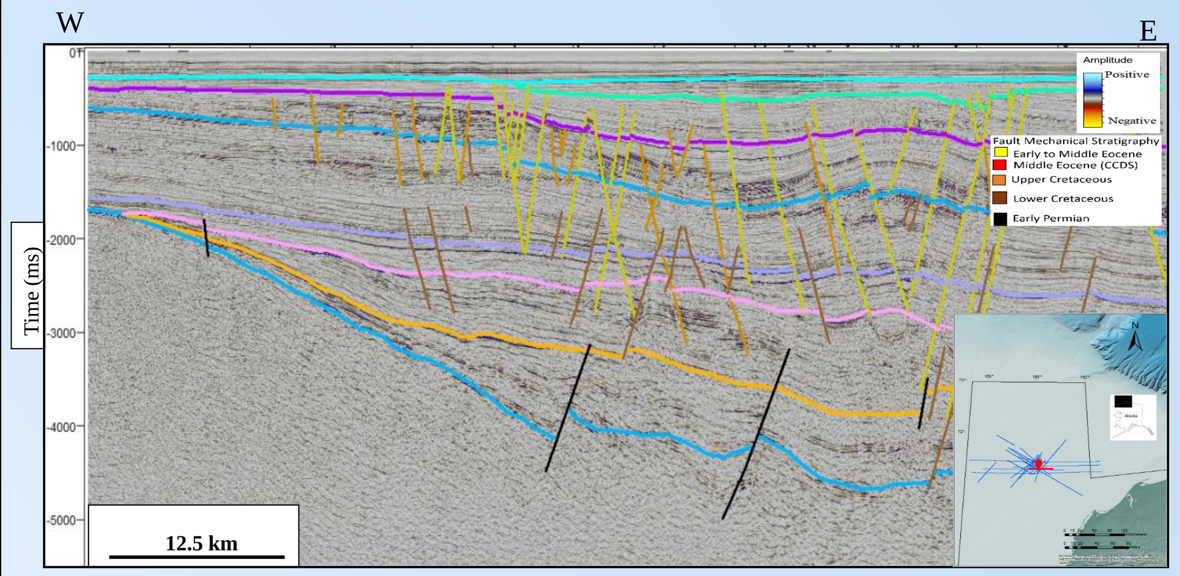

Figure 13 SFMS on line missing faults related to the impact structure.

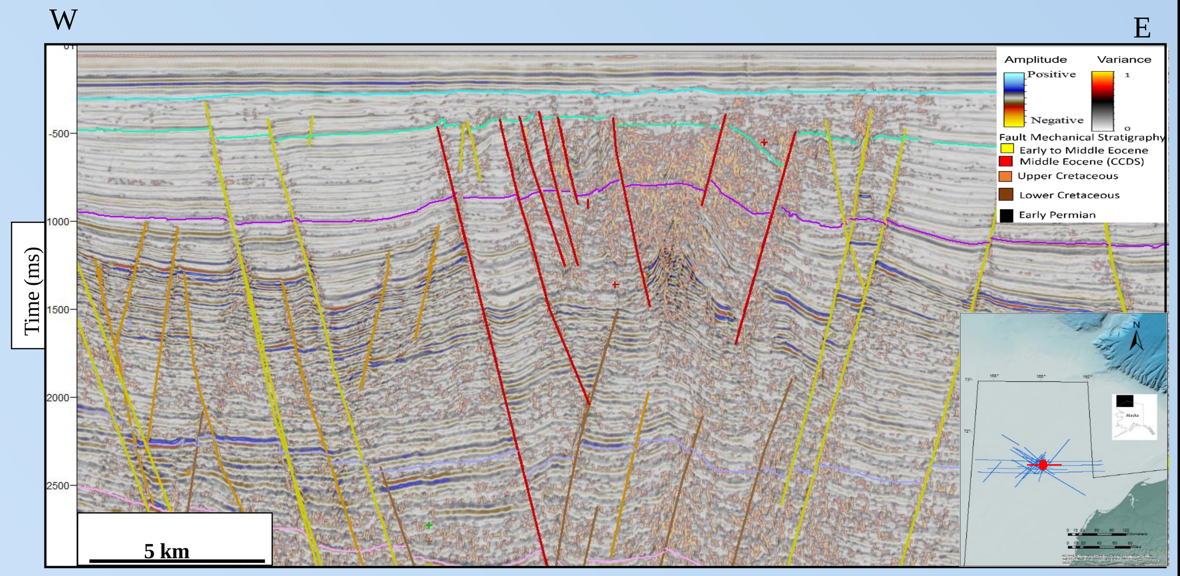

Figure 14 SFMS on faults related to the impact structure.

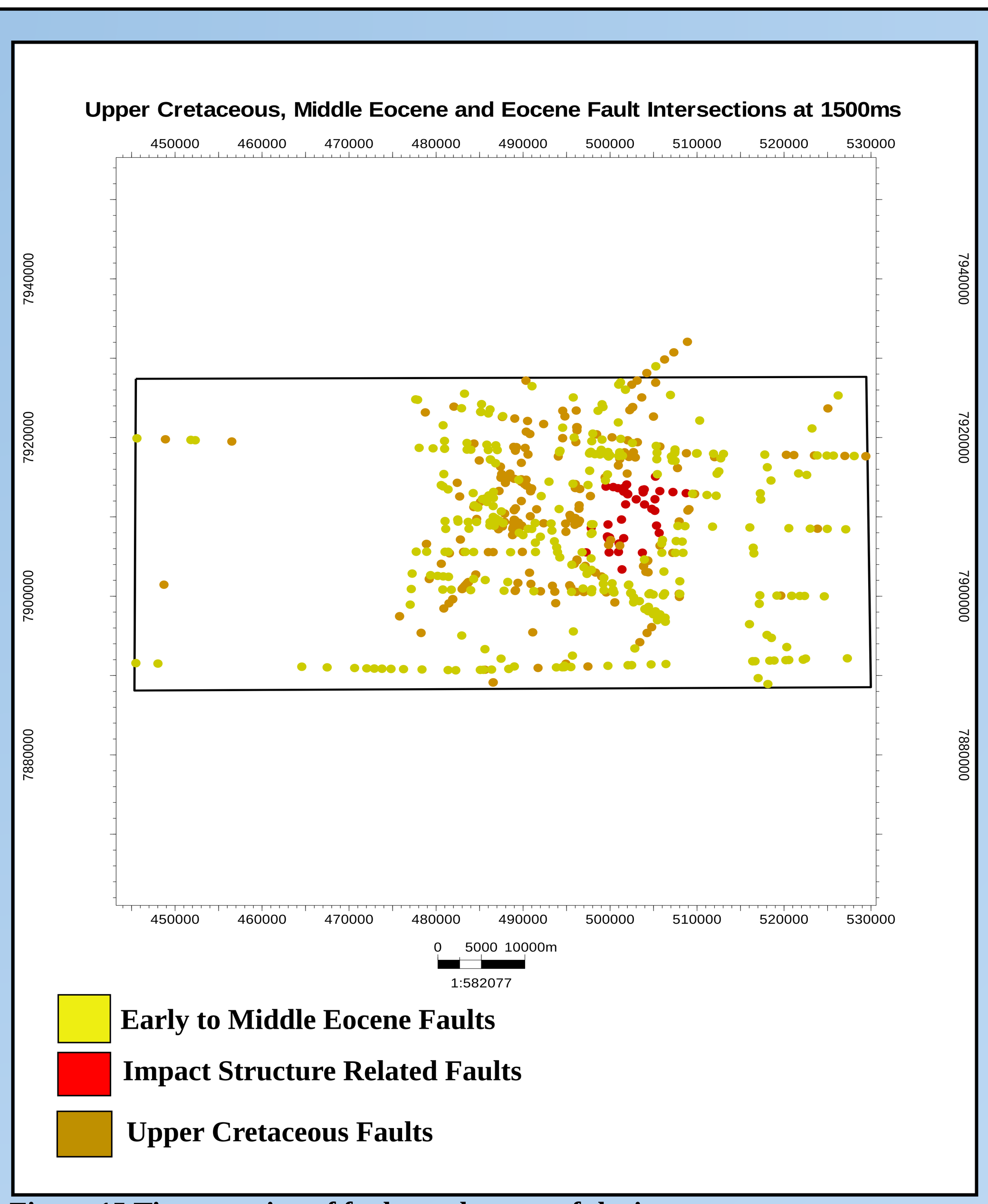

Figure 15 Time crossing of faults at the area of the impact structure at 1500ms.

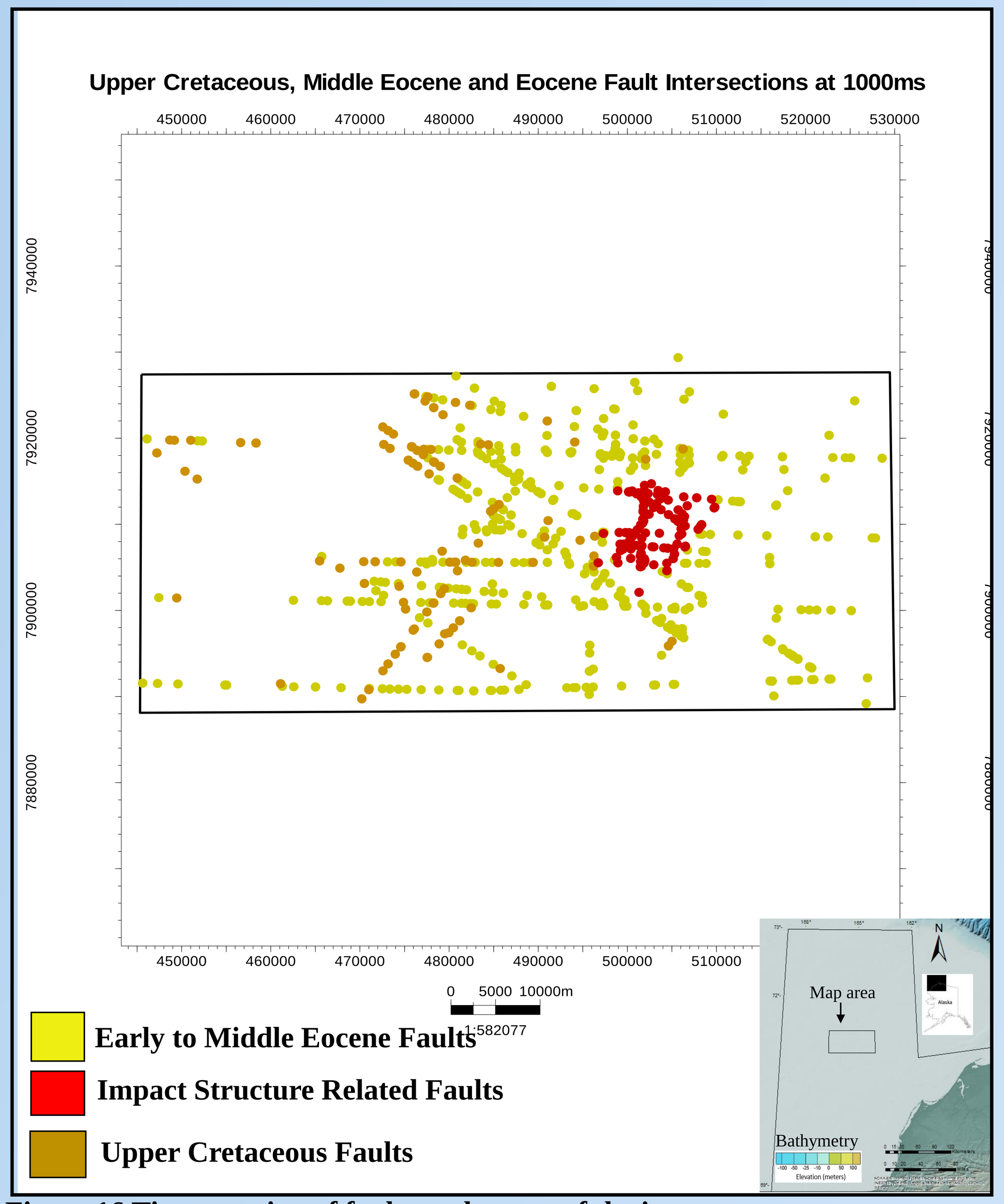

Figure 16 Time crossing of faults at the area of the impact structure at 1000ms.

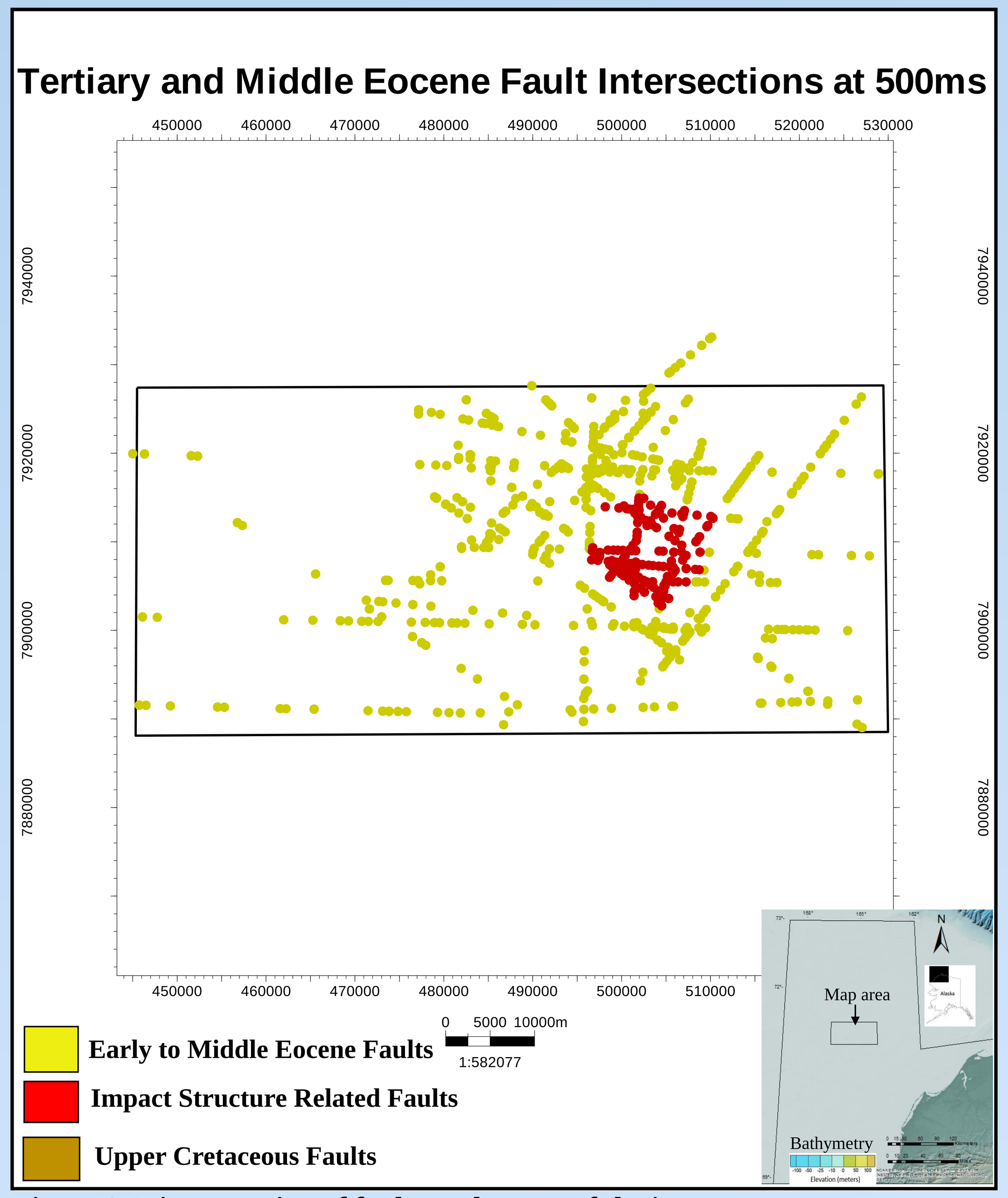

Figure 17 Time crossing of faults at the area of the impact structure at 1000ms.

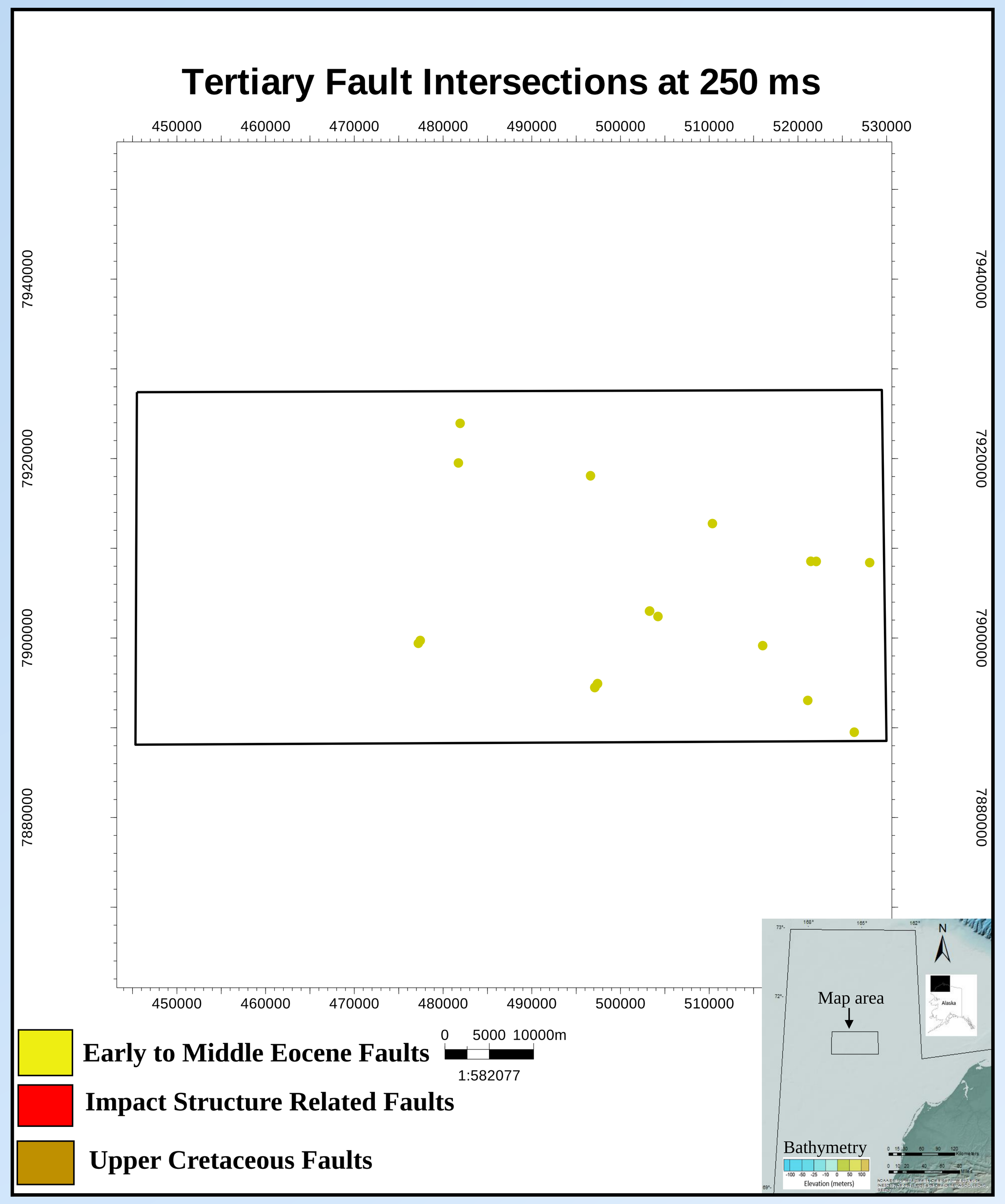

Figure 18 Time crossing of faults at the area of the impact structure at 1000ms.

5. Conclusions:

- Since the faults associated to complex impact cratering occur within a range of minutes, their SFMS is constrained to only one stratigraphic boundary, unlike many endogenic structures.
- In the case of the impact structure in the Chukchi Sea, the vertical range and the trace fault differs from endogenic faults of similar age, indicating a different deformation style.
- Derived from fault interpretation, the tectonic stress regime also plays a crucial role in the identification of these structures.

6. References:

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Pigott, J. D., and M. O. Abouelresh, 201, Basin deconstruction-construction: Seeking thermal tectonic consistency through the integration of geochemical thermal indicators and seismic fault mechanical stratigraphy-Example from Faras Field, North Western Desert, Egypt: Journal of African Earth Sciences, v. 114, p. 110-124, doi 10.1016/j.jafrearsci.2015.11.006.

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