On the Issue of Barents-Kara Region Basement Age, Russian Arctic*

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Abstract

The basement of the Barents-Kara region is a foot of the vast sedimentary megabasin from which proved and predicted reserves for hydrocarbons is tremendous. This is one reason the geology-geophysical study of Barents and Kara seas is notably more extensive than other Russian Arctic seas. Though there is no consensus on the age of the Barents-Kara region basement, some researchers consider the basement as blocks of uneven-aged consolidation and folded belts with different ages of final deformation (Gramberg et al., 2004). Others believe the entire Barents-Kara region is pre-Upper Riphean age for the metamorphic basement, which is overlaid by an intermediate structural stage of heterogenic constitution with rifted troughs filled by synrift associations which are in turn are overlapped by common Mesozoic sedimentary cover (Verba and Ivanov, 2009). Rifting, mainly of Permian-Triassic age, is thought to be the reason for cardinal reorganization of pre-Mesozoic basement structure in the region, and even partial oceanic crust forming on the primary continental crust. These extreme points of view are complemented with interpretation of the basement age in specific tectonic structures.

The Barents and Kara seas are mainly studied by geophysical methods, including CDP seismic for sedimentary cover, correlation refraction and DSS methods for the deeper crust and airborne gravity and magnetic surveys for identification of aperiodities. Of numerous methods, only CDP allows obtaining section dynamic behaviors and delineating extensive seismo-stratigraphic horizons. Their regional correlation and linking with land and island geology, augmented with deep well cores, allows distinguishing the sedimentary cover on seismo-complexes and to determine their chronostratigraphy.

Basement Investigation

In deformed and deeply metamorphosed rocks below the sedimentary cover, basement boundary CDP does not work. As it was that someone reasonably remarked “where stratification stops, geology is also finished”. Interpretation of results of both the correlation refraction method and DSS is invalid from the chronostratigraphic position. One must not judge hypothesized rocks composition according to seismic boundary wave velocity as well, all the more there is a lack of information about rock composition of the lower part of the sedimentary cover and basement. It is known that boundary velocities in Jurassic terrigenous rocks in the Grumantskaya well from Spitsbergen achieve 4.5 km/s, while in more ancient Triassic rocks of the Nagurskaya well in Franz Josef Land velocities do not exceed 3.2 km/s. The “granite” seismic velocities are not rare in carbon-bearing rocks - examples are plentiful.

The super deep Cola borehole revealed drastic contradictions between geophysical and petrological-geological ideas about the structure and composition of the lower crust. The Conrad boundary was supposed to be at the depth of 5-7 km, below this boundary, according to seismic velocities, was to be consistent basic rocks. However, up to the depth of 12.5 km were revealed exclusively granite-gneiss formations with an age up to 3 billion years. The nature of refracted waves remains unknown. So, the extensive refracted horizon with velocities 6.0-6.5 km/s on the key profile 3-AP in the South Kara region is inside the seismic transparent reflective wave field typical for basement. There are no profiles were one can observe the full correlation among refraction (refraction method) and reflective (CDP method) horizons (Figure 1). A similar situation is observed on profile 2-AP in the North Barents Basin where the refractive horizon also intersects different reflective horizons.

As shown in 2005 for the first time, for most of the South Kara Syneclise, an offshore continuation of the West Siberia Plate, the basement is Hercynian. The areal offshore structural reconstructions executed by the authors for the foot of Permian-Triassic deposits and wave field analysis showed that the negative South Kara Syneclise structures in Permian and Lower-Middle Triassic were intermountain depressions and troughs of hemiconcentric and concentric configuration (Petrov et al., 2005). They were formed in the orogenic phase of Hercynian expansion which occurred centrally in the most immersed area of the Syneclise, including North Siberia threshold and Northern Taimyr. Hercynian and other old folded complexes of the northern part of the West Siberia Plate have no Kara Shelf continuation. They are limited by an area of Early Cimmerian folds of the Yamal-Pai-Hoy Saddle which connected even-aged folded belts of Novaya Zemlya and South Taimyr. It was established that Permian-Triassic rifts marked in the central areas of West Siberia have no shelf continuation. Their absence at the onshore of West Siberia Plate (Purgydanskaya Syneclise) had been earlier indicated by N.Ya. Kunin et al. (1982) and L.Sh. Girshgorn et al. (1987-88).

Basement of the north part of Kara Shelf is pre-Upper Riphean which is clearly fixed on the 4-AP seismic profile (Figure 4) (Daragan-Suschova et al., 2011); Upper Riphean-Cambrian strata occur unconformably above. On the Severnaya Zemlya Archipelago these strata are represented by terrigeneous flysh and molass formations. In the modern structure of Severnaya Zemlya these basal series are fixed only in the troughs, where their thickness increases up to 7 km; in adjacent rises they are virtually absent. This is well illustrated by the wave field on the seismic profile situated between Vize Island and Franz Josef Land Archipelago (Figure 2). Here, since picket (PK) 160 in the southeast direction one can see erosion surfaces and scours of almost all Lower and Middle Paleozoic up to the lowest Rf3-V strata. The lower unit after the fracture zone, located northwest of the PK 160, wrinkled in relatively low-frequency folds. Perhaps on this wave field we observe an eastern border of presumably Vendian folding observed in the Nagurskaya well on Alexandra Island of the Franz Josef Land Archipelago.

According to CDP data, supplemented with borehole data and determination of magmatic and metamorphic rocks geochronology ages, the basement of the Pechora Plate is Baikalian (Daragan-Suschova, 1991). After a short Cambrian break, a thick molass series accumulated here, which is unconformably overlapped by terrigeneous and then carbonaceous Ordovician-Silurian deposits. This is illustrated by the modern seismic profile 3-AP, a part of which is showed on Figure 3a.

The basement of the Barents Sea Shelf is uneven-aged. Under the South Barents Basin adjacent to the Pechora Plate (profiles AP-3, KS-104) the basement is Baikalian (Figure 3b). This conclusion can be drawn on the basis of the complete identity of wave fields (Figure 3a and 3b). Although Figure 3b represents only the southern section of the KS-104 profile, features of the wave field characterizing the basement and interval below the basement are saved under the South Barents Basin and farther northwest of the profile.

Under the North Barents Basin basement, age varies from pre-Devonian to pre-Ordovician depending on interpretation (Figure 4). Overlying sedimentary cover with a thickness up to 18 km is represented with strata that has not been dislocated and without angular disconformity, formed as a result of continuous sedimentation in an evenly subsiding basin with partial conversion in certain stages of development. Towards the northwest and southeast of North Barents Basin for quite a long zone of seismic record breakdowns the basement is pre-Upper Riphean (profile AP-4). At the north island of Novaya Zemlya the basement is not younger, where Precambrian formations take part in Early Cimmerian crustal foundation. Here in the North Sulmeneva inlet a series of marbles and crystalline schists with amphibolites, metamorphosed in the epidote-amphibolite facies and injected by pegmatoid granites, are widespread. According to the latest results of isotope dating, the age of the series is Baikalian. The basement under Franz Josef Land is presumably Vendian (Figure 2), though according to recent data it may be more ancient (Stolbov et al., 2006)**.**

Taking into account dynamic behaviors of basement-cover boundary and the existing complexity of stratigraphic indexation of lower strata of the North Barents Basin sedimentary cover (profile AP-4 in Figure 4), we can find another explanation of enclave nature with “young” basement in the middle of older surroundings. The basement under the basin is neogenic, it came into existence as a consequence of vertical accretion, notably increasing of consolidated crust for account of lower parts of sedimentary cover as a result of sialisation and granitization at the boundary of petrostructurally and rheologically contrast mediums (Leonov, 2002). No folded Caledonian movements as some researchers supposed at Barents Shelf are fixed, except for the southern part of the Norwegian waters. At the same time in the North part of Novaya Zemlya, Middle Carboniferous-Permian strata overlap different levels of the Early Devonian-Early Carboniferous, which indicates block movements of this area in Late Caledonian or Early Hercynian time. Even-aged stratigraphic disagreement is assumed for the Admiralty Arch; however, folded deformations had not occurred here either.

Another example of neogenics is the sharp horizon inside the Baikalian basement of the Pechora Plate and South Barents Basin, traced by CDP on profiles AP-3, KS-104 (Figure 3). This reflective horizon, having gradual, smooth outlines not conformal to the rough top of the Baikalian complex, undoubtedly fixes regional density heterogeneity in the crust not associated with a particular stratigraphic event. The marked out horizon provides an excellent opportunity for integration of seismic reflection CDP and refraction methods.

Conclusions

A large number of interpretational versions of basement age are largely due to the simplification of different methods. Refracted horizons are not linked with reflecting horizons CDP (Figure 1). Problems with coordination of gravity and seismic fields are well known: the interpretation of the dependence on the speed-density multivariable usually requires a priori assumptions. The task becomes complicated by the phenomenon of convergence, which is widely distributed in animate and inanimate nature.

With simplicity comes about variants of assumptions concerning existence of early consolidated blocks within the limits of folded areas based mainly on interpretation of gravity and magnetic data and refraction methods data. If assumption for an earlier pre-Riphean consolidation of the Bol'shezemel'skiy and Pechoramorskiy arches of Baikalides of the Pechora Plate is quite acceptable (there are boreholes), the assumption of the Karelian age of the crystalline basement of the most loaded parts of the South Kara and Purgydanskaya syneclises has no factual basis. And why not Caledonian, Baikalian, Grenvillian or Gothic age? And then pre-Hercynian basement will not necessarily be crystalline.

There are often attempts of too broad interpretation of CDP chronostratigraphy resources. The CDP method is typically used for studying only non-dislocated and non-metamorphosed layered or almost layered mediums. Sections with remnant stratification within folded basement of sedimentary basins sometimes highlighted inside seismically transparent strata, which in this case are interpreted as troughs of riftogenic nature, or using refractive waves, are united in the intermediate sedimentary cover stage. The nature of sporadic sections with remnant stratification is obscure. Such stratification most likely means schistosity or the result of other superimposed activities such as metamorphism, fluid currents, fracturing, etc. Examples of pseudo layering in folded and metamorphic strata are well known to petrologists and structural geologists. Such interpretations can add useful information on the age of the sedimentary cover-basement boundary for large oil and gas bearing basins of the Barents-Kara region.

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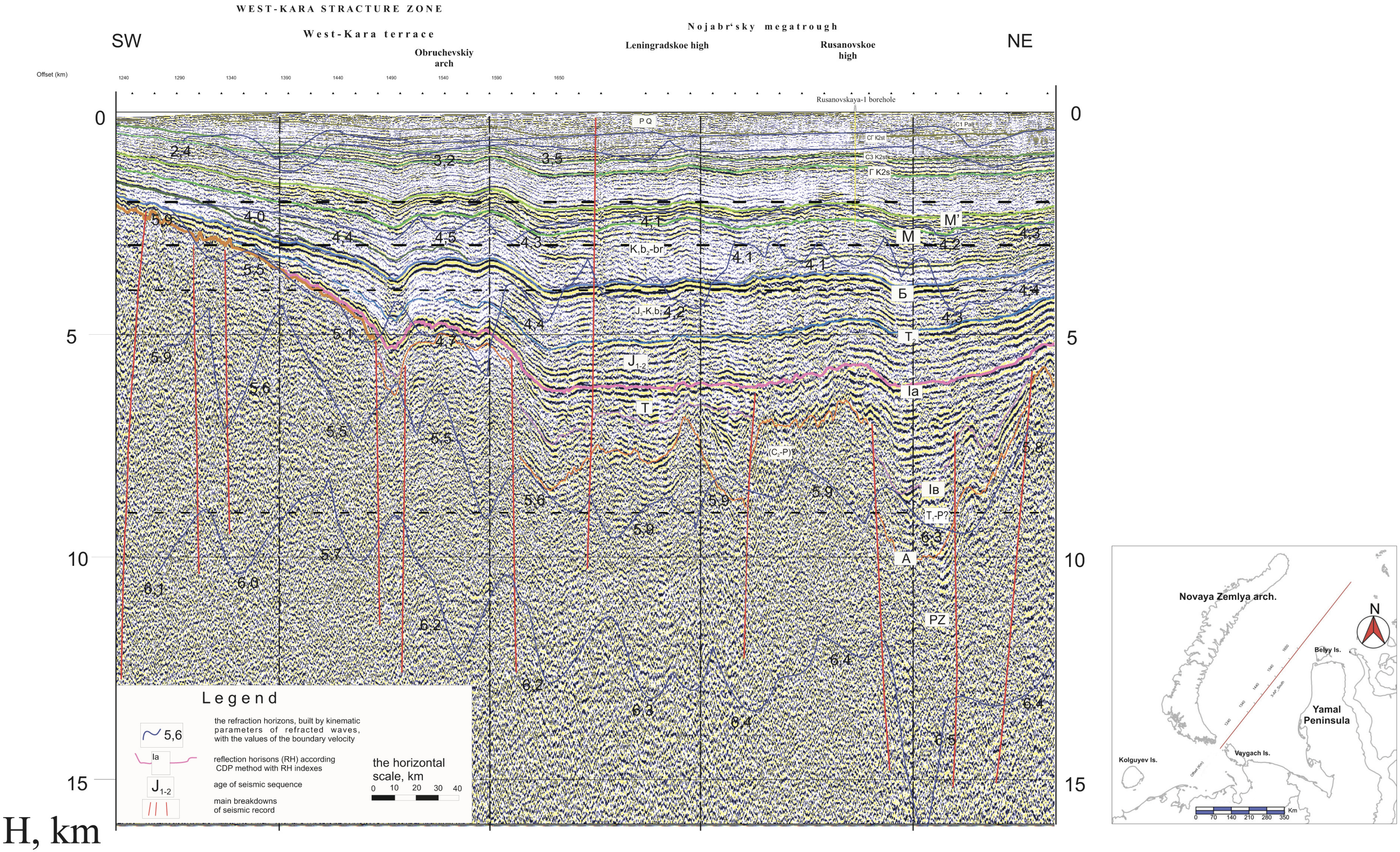

Figure 1. SW-NE Seismic profile across West Kara Structure Zone.

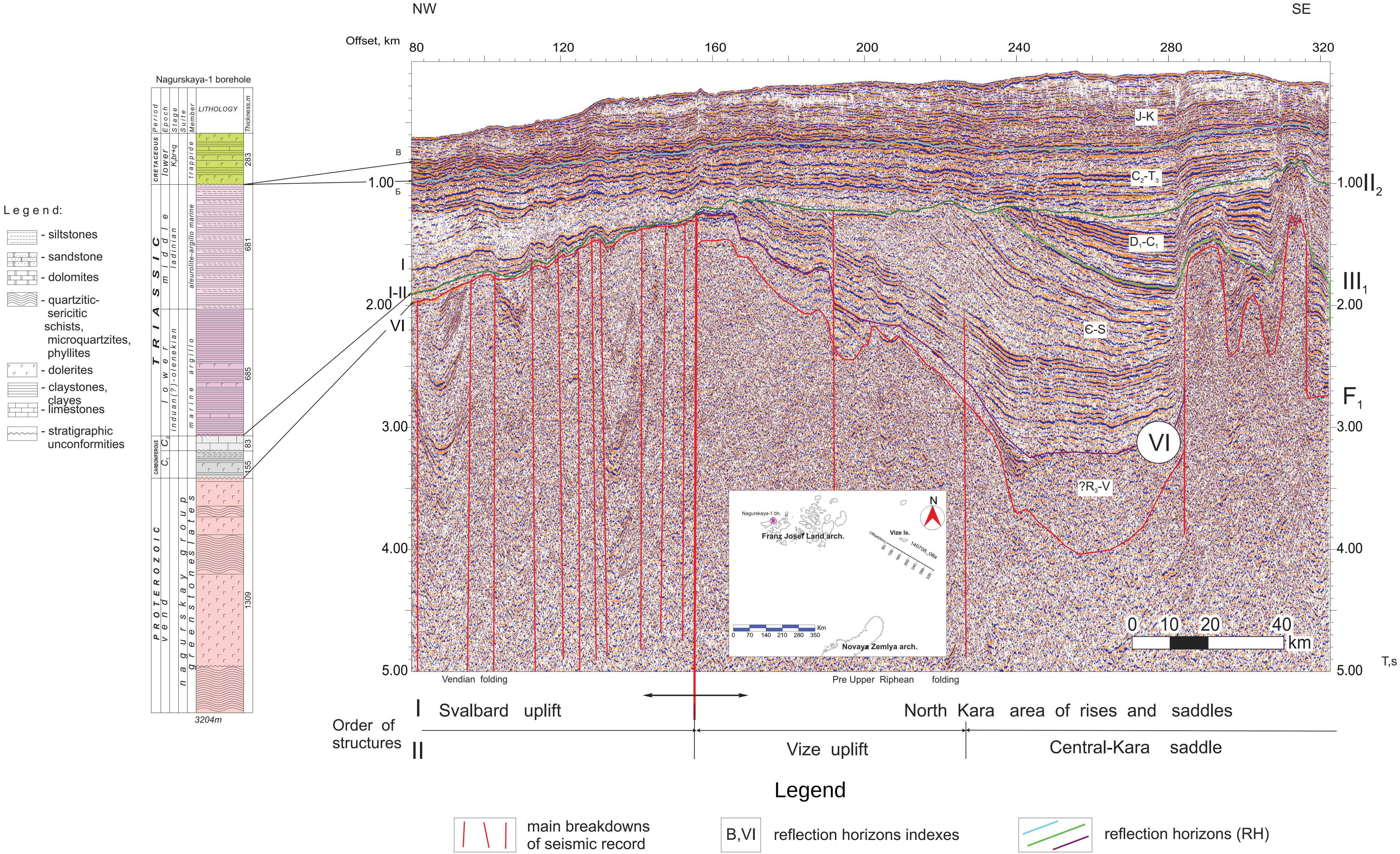

Figure 2. NE-SW seismic profile across Svalbard Uplift and North Kara area, with Stratigraphic column.

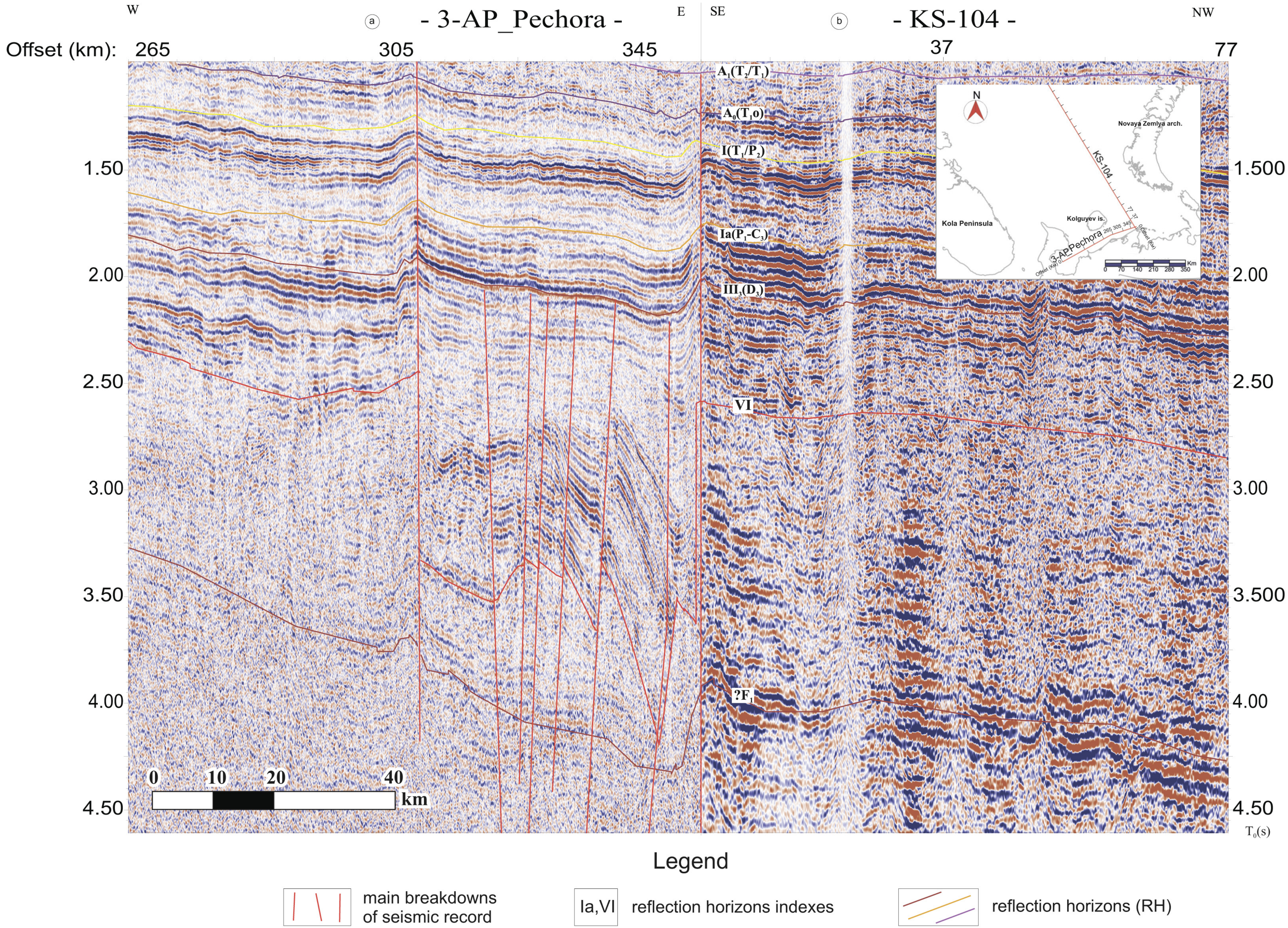

Figure 3. (a) W-E seismic profile 3-AP Pechora, and (b) SE-NW seismic profile KS-104.

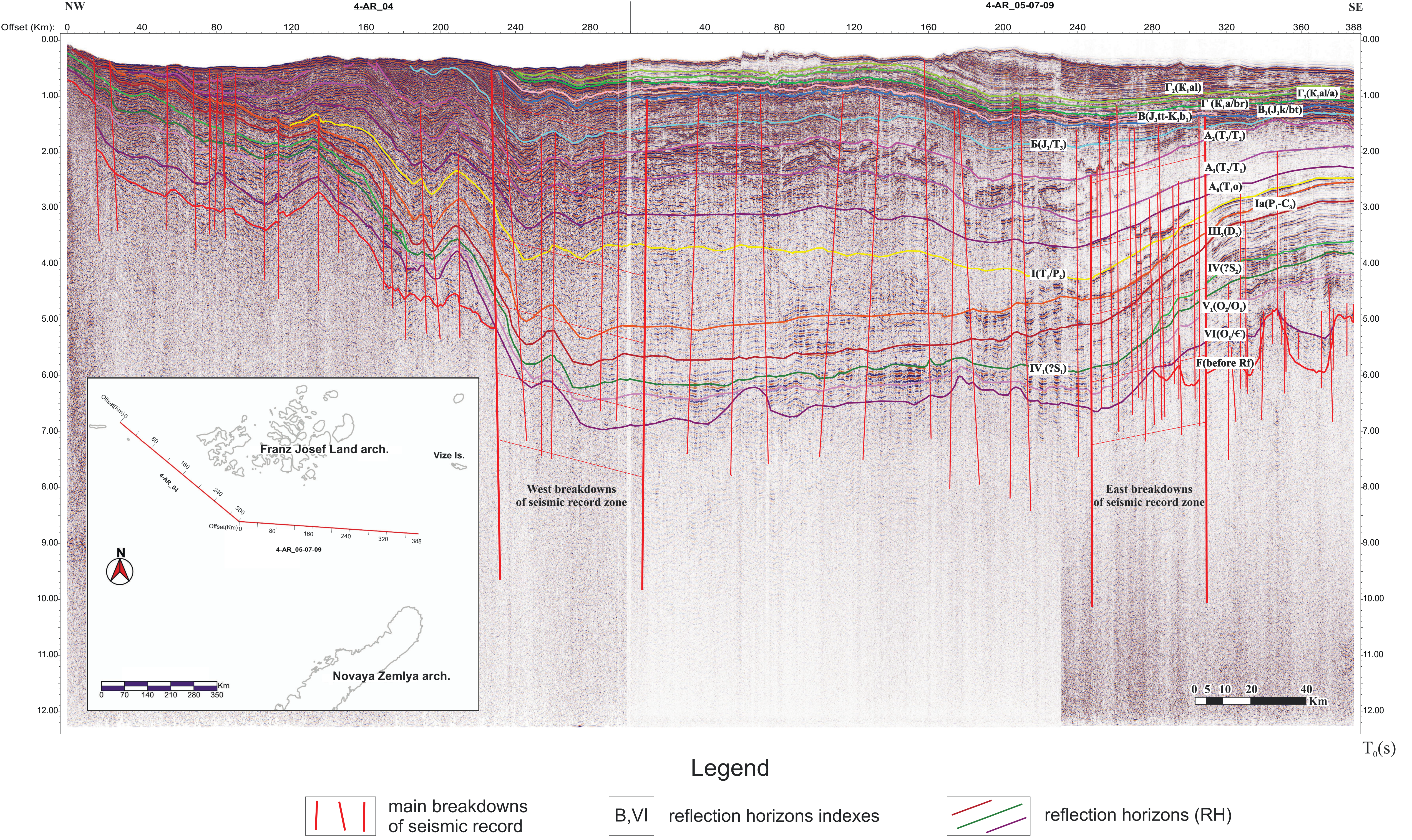

Figure 4. Connected NW-SE seismic profiles 4-AR_04 and 4-AR_05-07-09.