GPR Survey of Fortification Objects on Matua Island, Kuril archipelago

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Report Plan

- Historical reference
- Short characteristics of investigation media and objects
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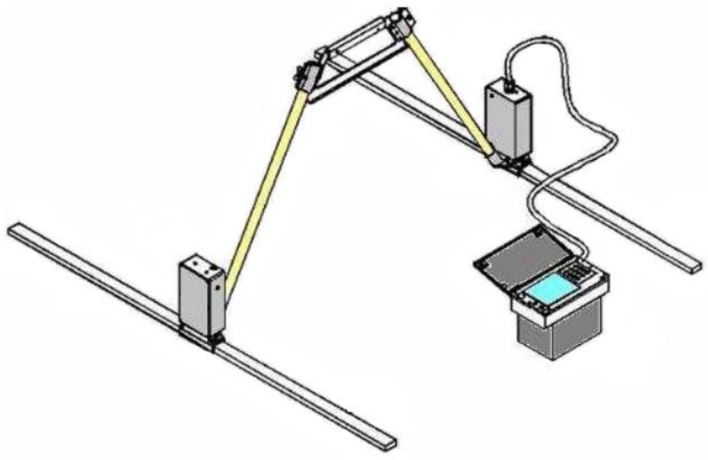
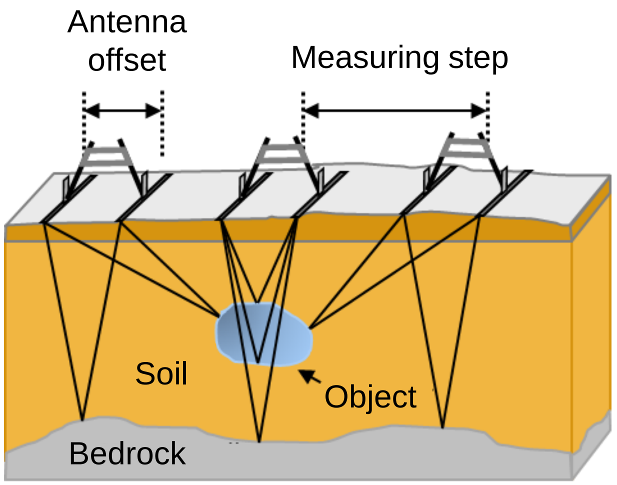
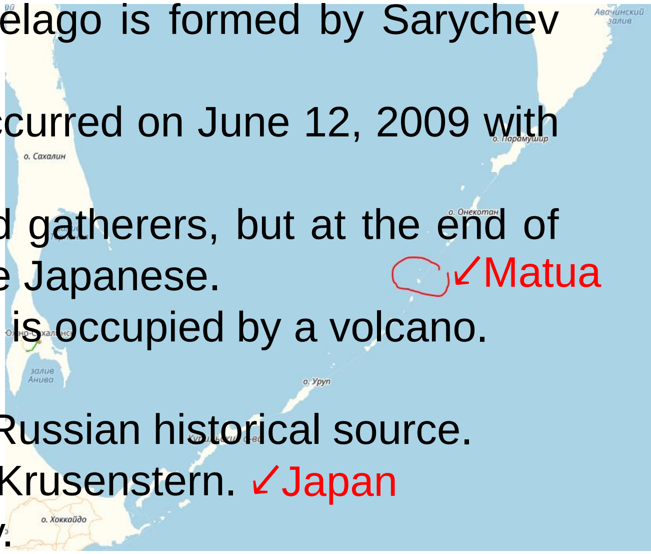
- Conclusions





Historical Reference

- Matua island located in the central part of Kuril archipelago is formed by Sarychev Peak – one of the most active volcanos in that region.
- The last powerful eruption of Sarychev Peak volcano occurred on June 12, 2009 with the release of ash clouds to a height of 16 km.
- The residents of the island were the Ainu - hunters and gatherers, but at the end of the 19th century they were evicted from the island by the Japanese.
- The island size is 11× 6.4 km. Half the area of the island is occupied by a volcano.
- Sarychev Peak (active volcano) has the height 1446 m.
- The year 1711 - the first mention about Matua Island in Russian historical source.
- The year 1813 - cartographic survey of the islands by I. Krusenstern.
- The Japanese appeared on the island in the XIX century.
- Japanese military activity on the island began from the late 30's, the XXth century.
- On August 25, 1945, the garrison of the island (3,811 men) capitulated without a fight.



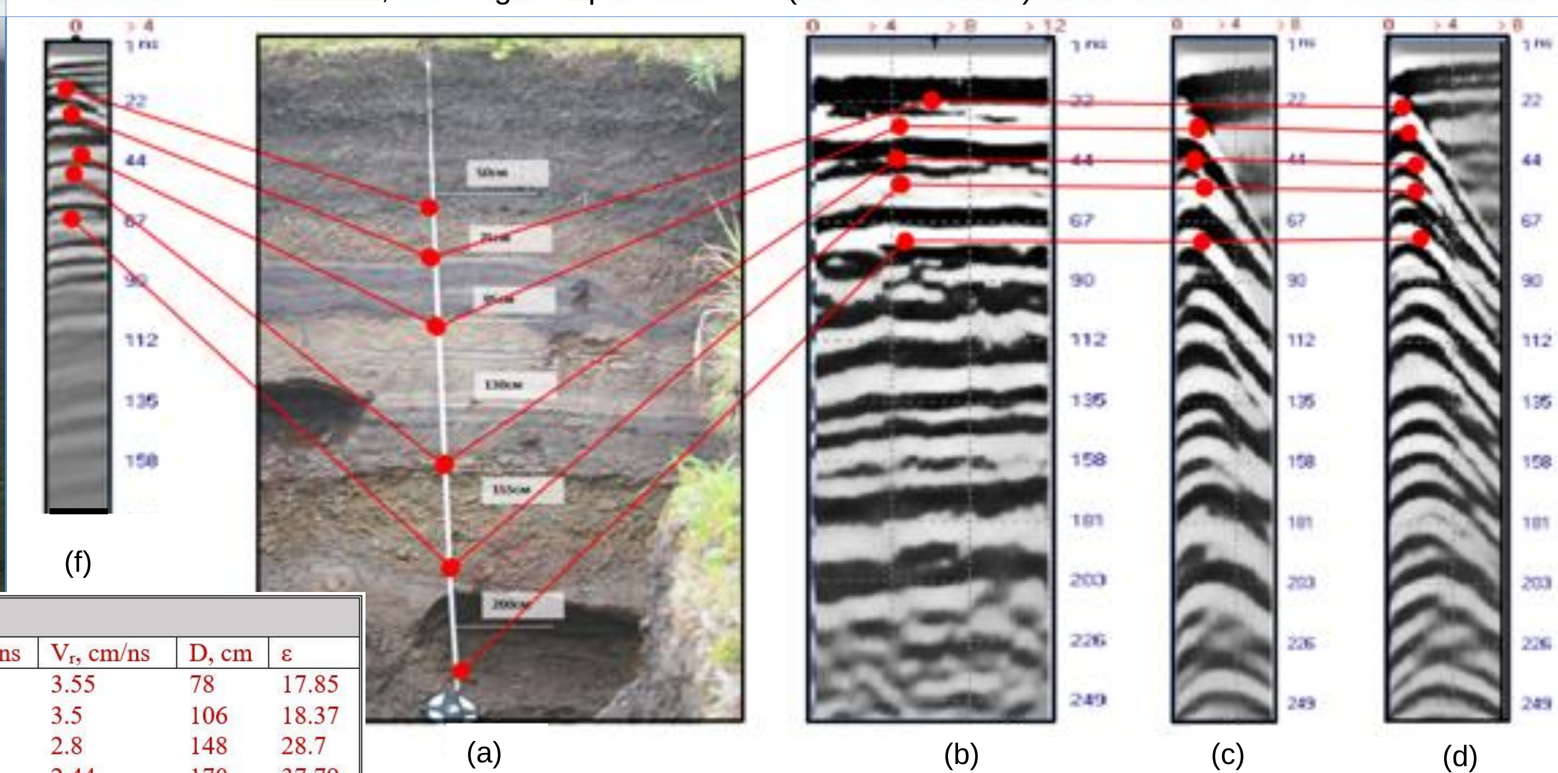
Now the island is uninhabited.

Short Characteristics of Investigation Media

- July-August 2017. The second stage of the complex expedition of the Defense Ministry of the Russian Federation and the All-Russian public organization "Russian Geographical Society" was held on the Matua island (Middle Kuriles).
- Volcanologists, soil scientists, biologists, divers, geophysicists and archaeologists from Moscow, Vladivostok, Kamchatka and Sakhalin took part in the expedition.
- Geophysical investigations of the island territory, search of objects of military-technical history and fortification, passportization of these objects were carried out. A complex survey of the coastal seabed by radio engineering means, controlled underwater vehicles and divers.
- A careful survey of engineering structures of the Second World War, including work on radar profiling was carried out at 9 sites. The total volume of the survey was 3515 meters of GPR profile.
- This work was supported in part by Russian Foundation for Basic Research, grant No. 18-02-00185.

Short Characteristic of Investigation Medium and Objects

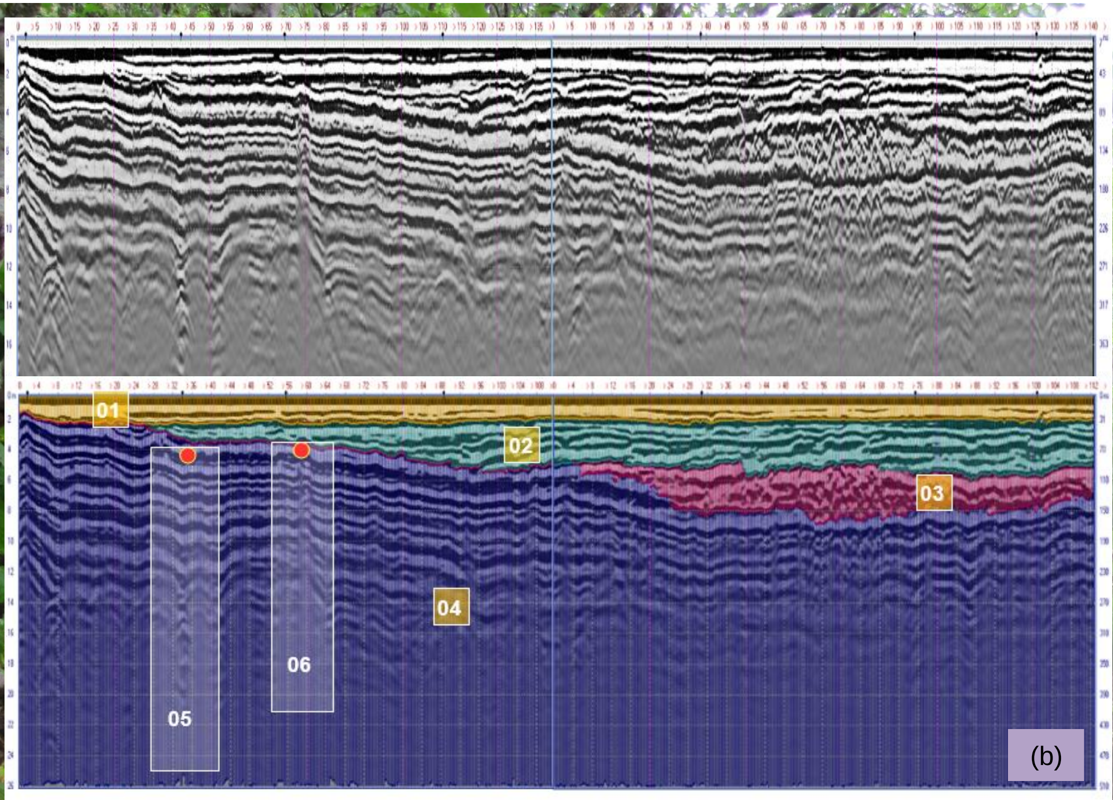
- Lots of objects of military engineering, field fortification and infrastructure.
- In the geological section (~ 10 m) at the Dvoynaya Bay, a full Holocene chronicle of the activity of Sarychev Peak volcano is recorded, containing more than 50 horizons of tephra.
- There is a characteristic alternation of layers of different thickness and different composition, from buried soils and fine ash to volcanic gravel. The thickness of the layers is from 5 cm to 1.5-5 meters, changing over the island and increasing from south to north.
- From the point of view of electrodynamics, a typical GPR section is formed from material layers with different permittivities and conductivities, creating multiple interfaces (coherence axes) on the GPR track.



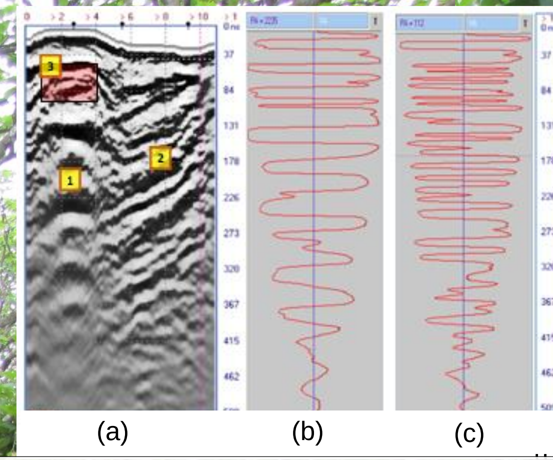
Hodograph				
Layer #	V_g, cm/ns	V_r, cm/ns	D, cm	ε
1	3.55	3.55	78	17.85
2	3.55	3.5	106	18.37
3	3.29	2.8	148	28.7
4	3.14	2.44	170	37.79
5	3.0	2.58	219	33.8
6	3.82	7.8	336	3.7
7	3.89	3.95	770	14.42

A comparison of GPR data and geological cross section: (a) – pit of 2 meter depth; (b) – part of B-scan; (c,d,f) – CMP data: 100 MHz (c), 150 MHz (d), 350 MHz (f).

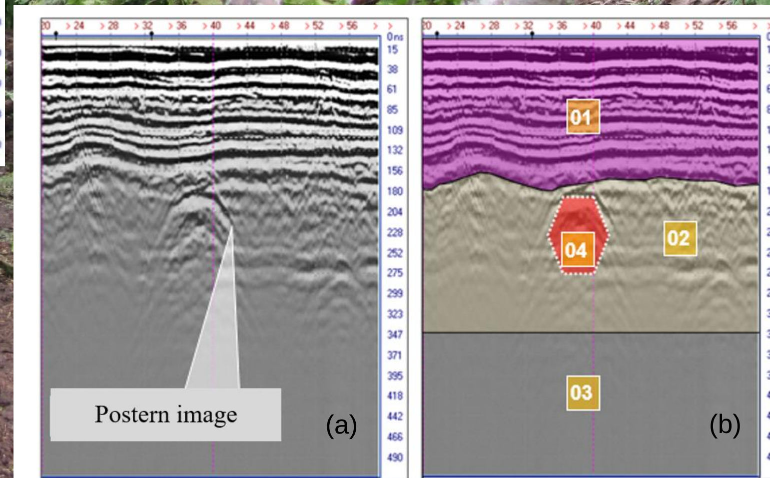
GPR probing results



The airfield. The GPR profile along the airfield sheet, antenna 100 MHz: (a) – the original profile; (б) – tinted radar complexes: (01) – airfield pavement complex; (02) – bulk soil complex; (03) – coarse volcanic slags and rock fragments; (04) – regular horizontally layered structure; (05), (06) – local objects.

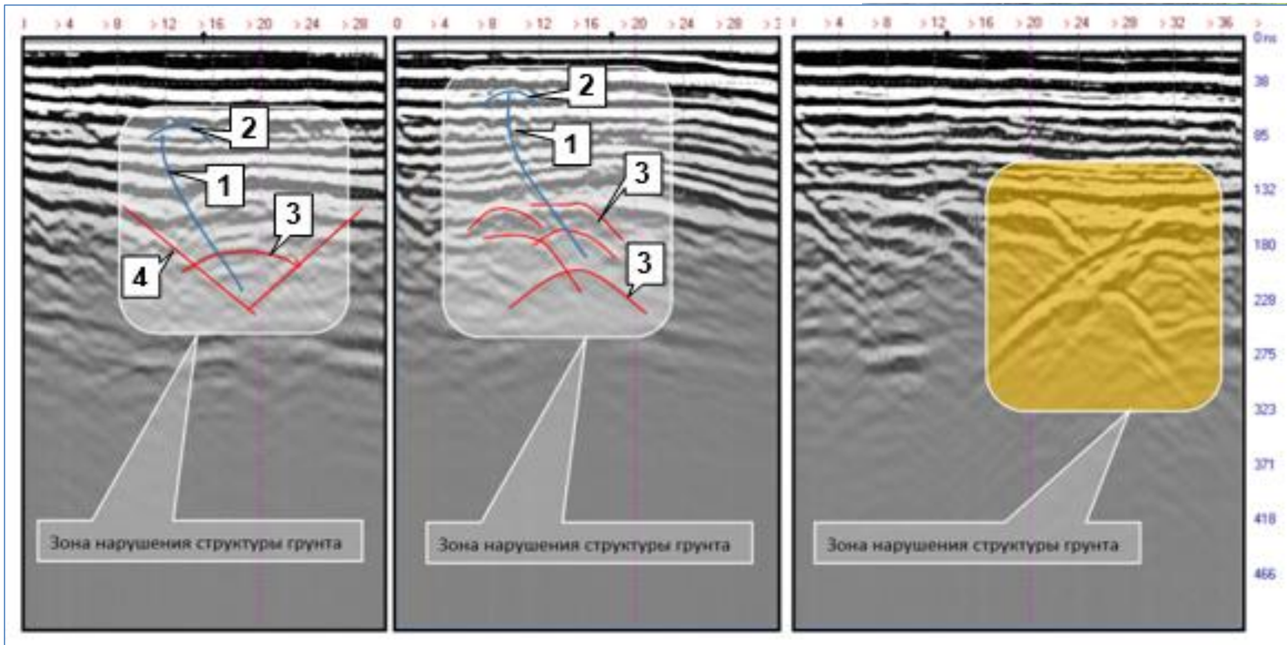


Artillery Pillbox : a) – B-scan, antenna 50 MHz; b) – A-scan, above pillbox (1) ; c) – A-scan, off the pillbox (2); (1) – the low-frequency area; (2) – the regular signal area; (3) – the pillbox.



Postern (tunnel): (a) – the original profile; (b) – tinted radar complexes; (01) – subhorizontal in-phase axes; (02) – complex with characteristic wave pattern; (03) – low-signal area; (04) – the postern.

GPR probing results



(a) (b) (c)

Profiles of "Artillery position":

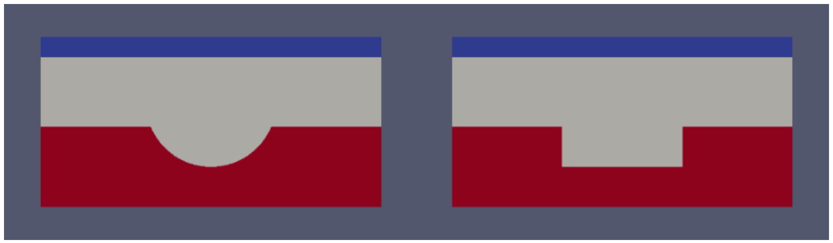
(a) – profile (03);
(b) – profile (04);
(c) – profile (02);

(1) – vertical line (discontinuity of the in-phase axis);
(2) – hyperbola at the top of the discontinuity line;
(3) – hyperbola formed by the decomposition region;
(4) – slip line of loose grounds.

- The radio-physical features, such as waveform variations, discontinuities in the phase coherence, numerous phase shifts of the signal, and the presence of multiple signal reflections, point to the presence of cracks and disturbances in the ground structure.
- The soil decompaction supposedly is associated with the destruction of a postern, underground rooms. Such destructions can be observed almost in the entire GPR B-scan.
- In the upper part of the B-scans, which are formed with the extended subhorizontal in-phase axes (up to 170-180 ns), disruptions manifest themselves as discontinuities and sharp changes of the axis shape.
- In the lower part of the B-scans, disruptions are appeared as a smooth bend of the in-phase axis or a characteristic hyperbola.

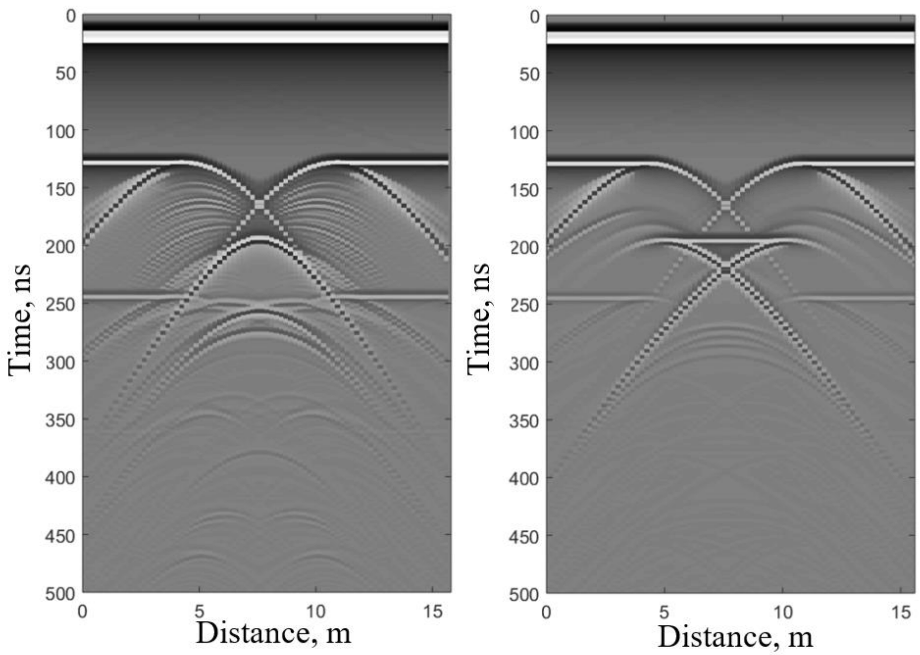
Modeling

- We performed 2D modeling using gprMax package
- The probing signal is "gaussiandot" pulse - the first derivative of the Gaussian function with a center frequency of 100 MHz: $I(t) = -4\pi^2 f^2 \left(t - 1/f\right)\exp(t - 1/f)^2$,
- Two supposed geometries of the dip (a,b);



(a) (b)

Assumed dip geometries



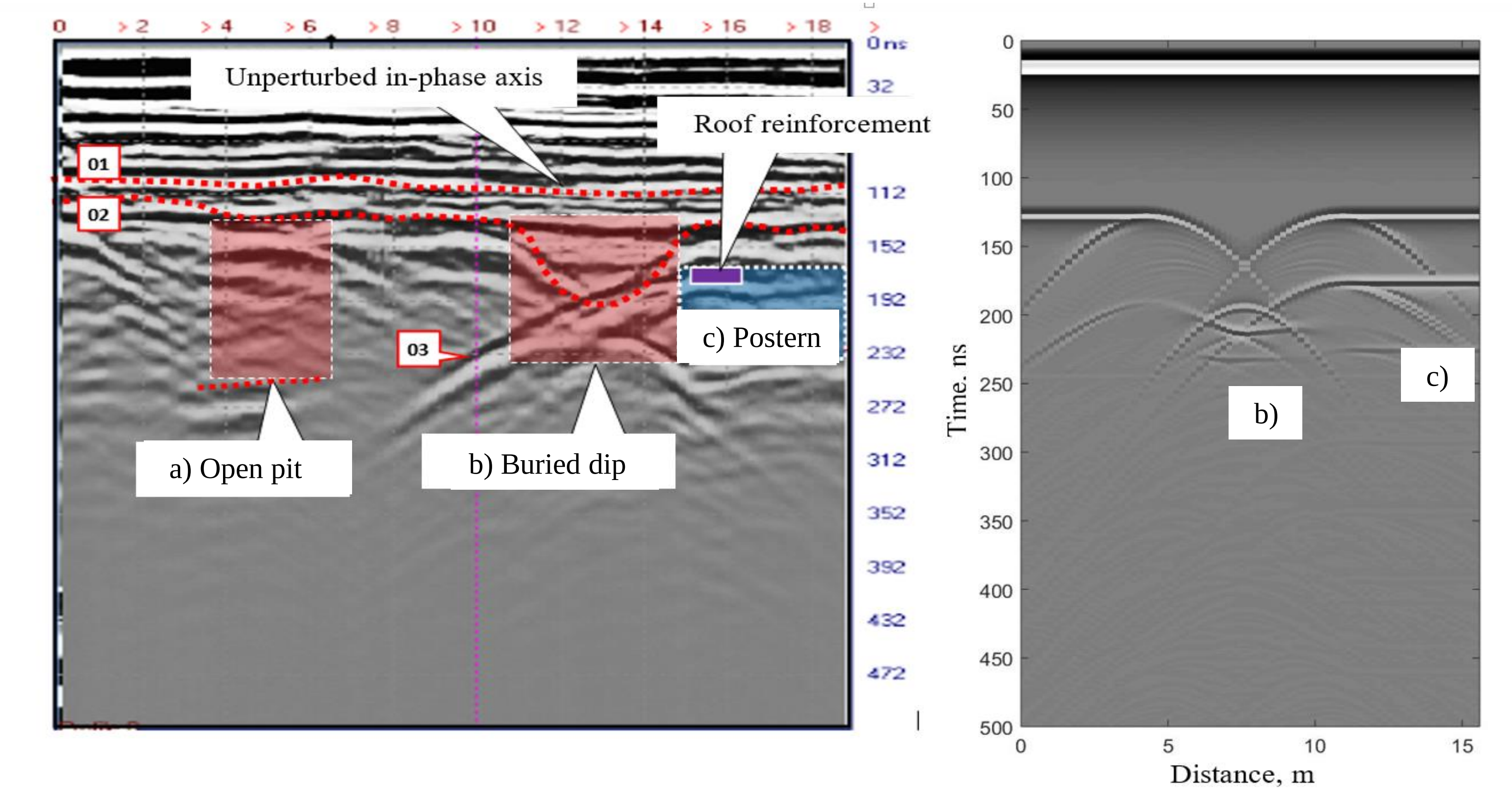
(c) (d)

Results of B-scan modeling for different dip configurations. mn

- Fig. (c). The failure creates on the B-scan a characteristic structure of the "swallowtail": the upper edges of the dip give hyperbolas, and its base corresponds to the center of the "tail".
- Fig. (d). On the B-scan, four hyperbolas are distinguished, corresponding to the angles of a rectangular dip, the bottom of the gap between the lower hyperbolas is clearly drawn.
- Conclusion: the structure of the dip has a shape close to that shown in Fig. (a).

Detailed modeling

- Here is a detailed interpretation of the radargram of preivous slide, Fig. (a).
- A cylindrical-shaped dip from the previous slide is taken as the basis.
- On the left, there is a trace of an open pit seen on the aerophotograph.
- In addition, one can recognize an undamaged postern to the right of the dip, its axis runs parallel to the profile path.



Conclusions

- GPR proved to be an efficient method of investigating the soil-pyroclastic cover of Matua island, as well as studying the rests of military engineering facilities of the Second World War.
- Using a high-power GPR with resistive-loaded (50-350 MHz) antennas allows one to detect objects at the depths up to 50 meters in multi-layered, electrically conducting soils where traditional GPR systems do not do well.
- Combination of standard software with specialized signal scattering models is useful for checking the GPR operator assumptions about the subsurface medium structure and the presence of hidden objects.

Thank you for your attention!