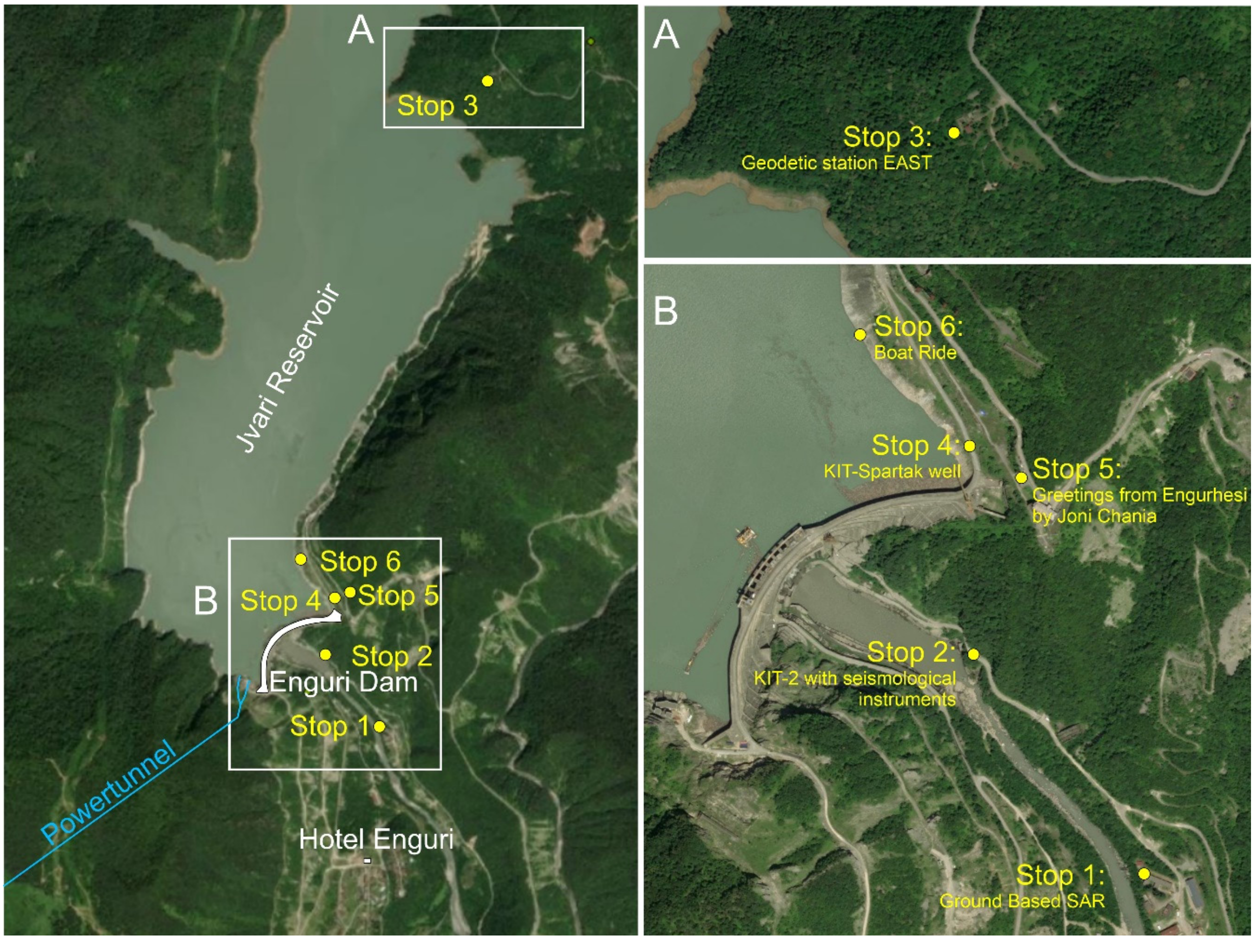
Field Trip Enguri Dam September 17 2022
Begin 9 a.m. at Hotel Enguri

General Information

Please wear robust clothing and especially good shoes and depending on weather conditions a light raincoat.
We have a lot of potential stations around Enguri Dam but we have chosen the closest installations to have a very condensed way to show you around. Our specialists are happy to answer your questions and can also explain which further equipment is installed e.g. upstream Enguri River.
The Enguri Dam is located at the top of the Enguri and Vardnili Cascade along the Enguri River and is with 271 m height one of the highest arch dams worldwide.
It was designed in the 1960s and built until 1986 with first power production in 1979, whereas the power plant is at a distance of about 15 km in Abkhazia. This is to increase power production from the differences in the topography between dam and the so-called powerhouse. The dam and the powerhouse are connected via a 15 km long and 9.5 m wide underground tunnel. About 450 m³ of water per second are transferred to the power station (for comparison: about 5 s to fill an Olympic pool).

Field Trip Overview

Start is Hotel Enguri 9 a.m. Please use the same car as for the travel from Tiflis to Enguri. This saves time at each stop.



Stop 1: Ground based SAR in front of Enguri Dam. Here you will have a great view from below to the giant dam and of course explanations of how this very special instrument is working and what we can learn from the data for the dam.

Stop 2: Seismological Station at boreholes KIT-2 and KIT-4. This is the site where new technology of seismometers has been installed. You will also get an overview on typical seismological field stations.

Stop 3: New geodetic installations at the former (now given up) geophysical observatory. You will get an impression of a geodetic field station and a short introduction into the measuring concept. Brief picnic which the ladies at the hotel have prepared for us.

Stop 4: Site of recently drilled KIT-Spartak well and first overview on Jvari Reservoir. Here we bring light into the underground. At stops 1 and 4 we also provide brief explanations on technical parts of the dam.

Stop 5: Overview Platform near the directors building of Engurhesi Ltd. with explanations about the building of the dam by Director Mebonia and Director Chania.Overview Platform near the E.

Stop 6: Marina. We will take a long staircase (good shoes) and some walk over uneven ground to the boats and have a boat trip on the Jvari Reservoir with possibility to have a look to the other side of the lake (hardly accessible without boat), on the ponton with the equipment for flushing and the inlet to the power tunnel. The colleagues have had many hours on the boats to check for the sediments inside the Jvari reservoir. The boat ride depends on weather and water conditions in the dam.

Stop 7: We will return to the hotel and enjoy dinner with local food.

Please be prepared for an evening (after dinner) visit inside the Enguri Dam with a special surprise for you!!

Geological Map of Enguri and Brief Geology Overview

The Caucasus is a major orogenic belt resulting from the Cenozoic collision between the Arabian and the Eurasian plates. The post-collisional sub-horizontal shortening of the Caucasus is caused by the northward motions of the African-Arabian plates and cumulates at hundreds of kilometres.

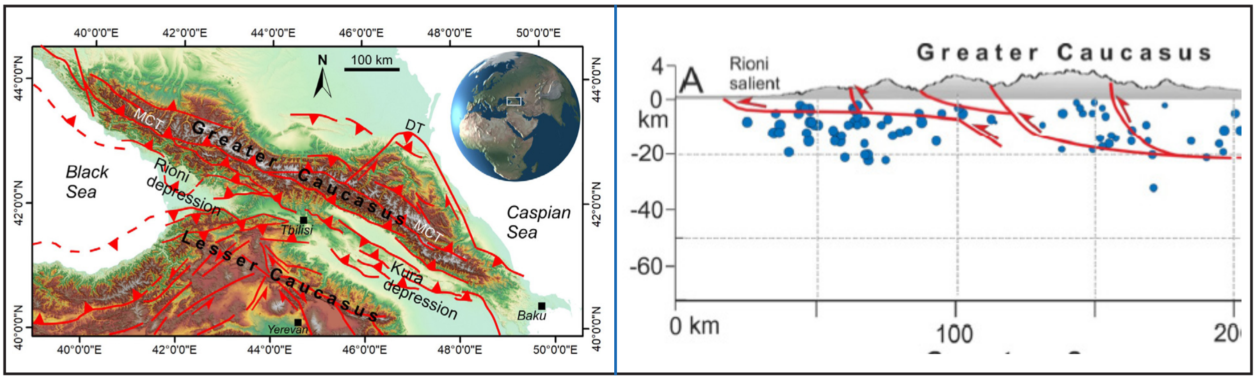


Fig. 1: Major fault systems in the Caucasus (left) and section across the western great Caucasus with earthquakes > magnitude 3.5 (Tibaldi et al., 2020).

GPS and seismic data indicate that the convergence between the Eurasian and the African-Arabian plates is ongoing. Therefore, the Caucasus is still tectonically active, with vertical and horizontal components of motions that imply ongoing mountain building processes. In this area the convergence rate, with about 1 to 3 mm/y is relatively low compared with the eastern great Caucasus were the convergence rate reaches up to 15 mm/y.

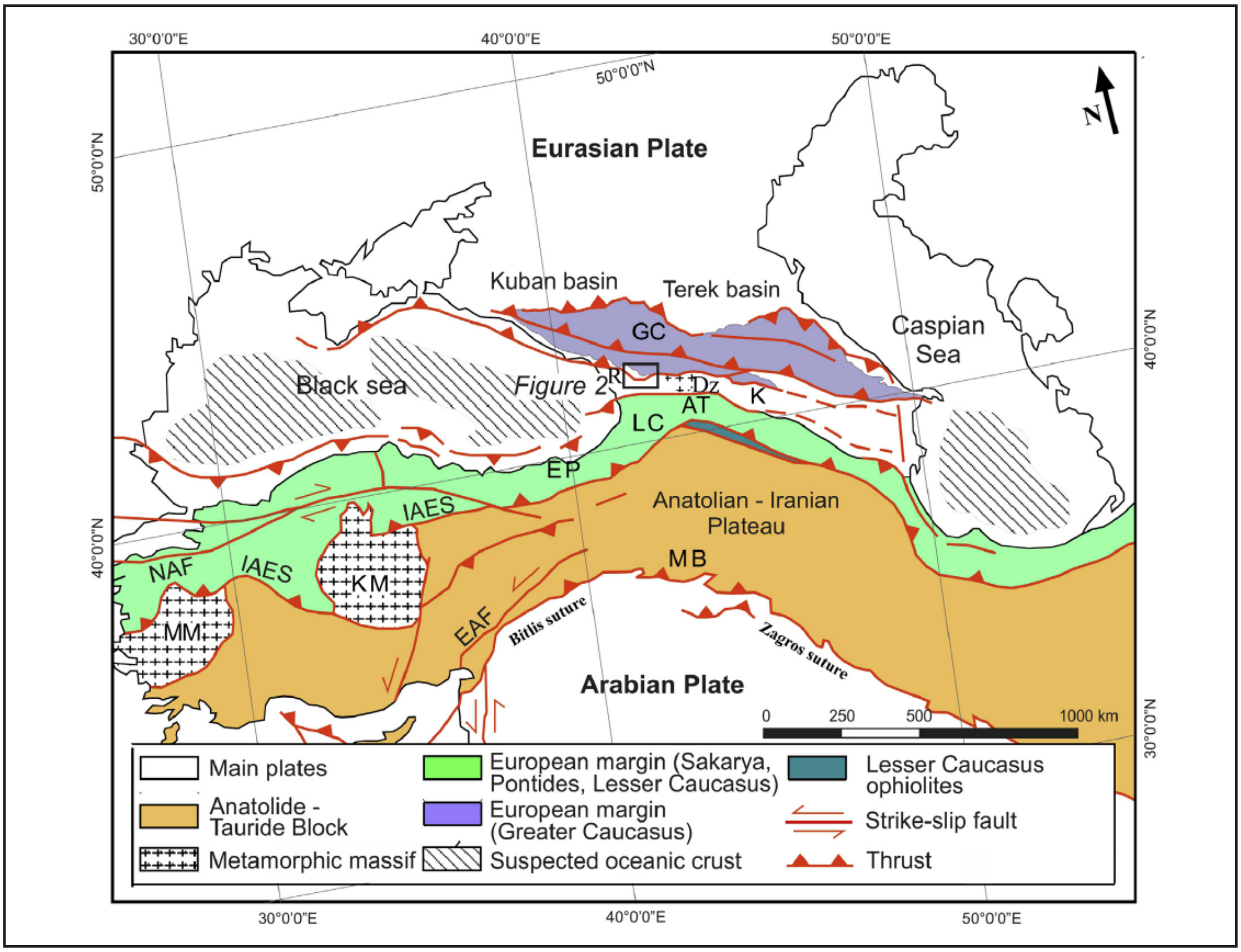


Fig. 2: Tectonic Map of the Arabia-Eurasia collision Zone according to Sosson et al., 2010. The maximum horizontal stress is perpendicular to the Thrusts.

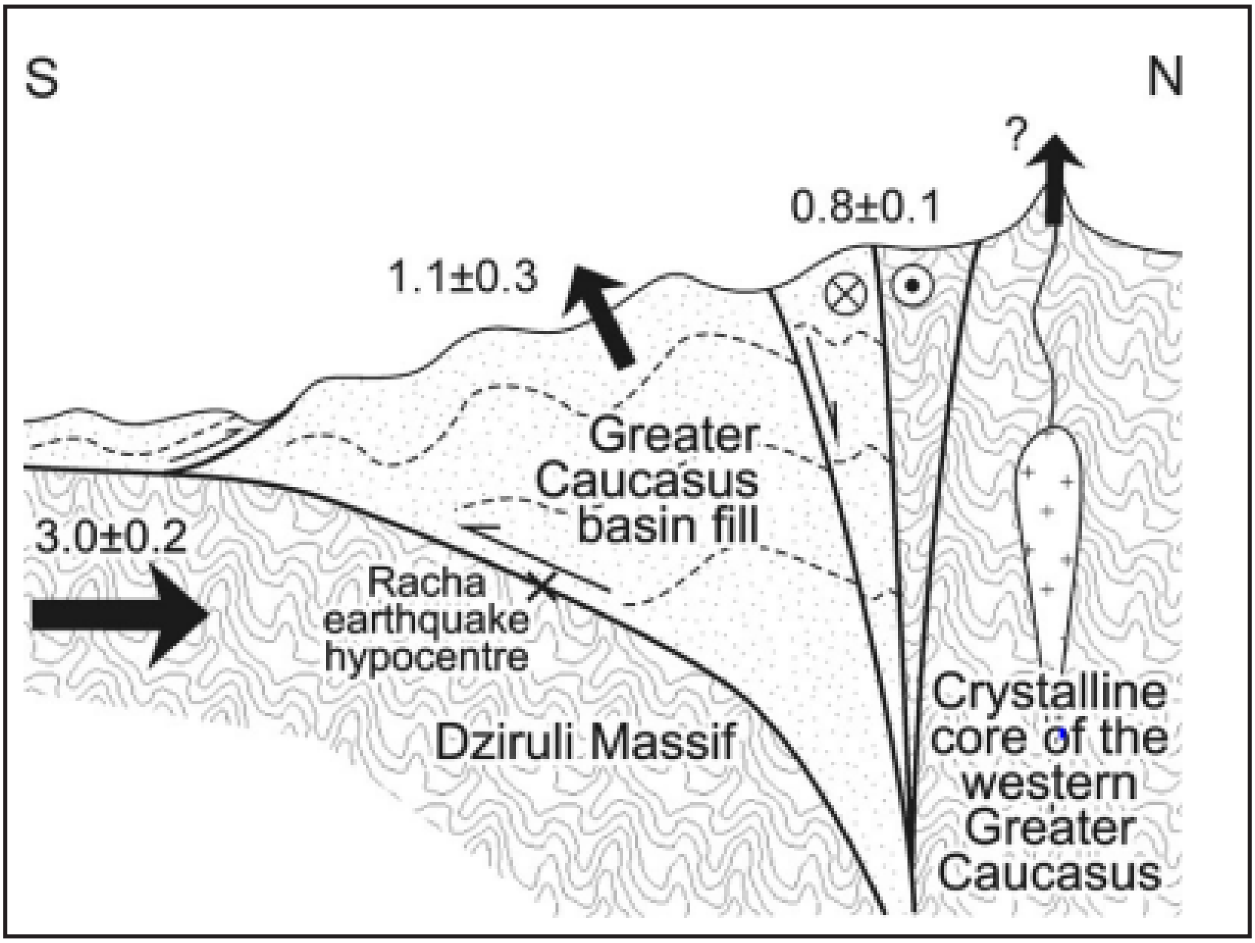


Fig. 3: Cartoon showing a possible mechanism for the present-day rapid exhumation of the southern part of the western Greater Caucasus in West Georgia. Rates are in mm a−1 (km Ma−1) and are derived from Reilinger et al. (2006) and Vincent, S. J. et al. 2011.

The structural data previously obtained from old geological maps were verified in the field using various indicators. These indicators include deformed and offset layers, crushed or brecciated rock material (Fig. 4), secondary mineralization along fractures, and especially slickensides (Fig. 5).

Fig. 4: View of one of the two fault zones identified in the field at Enguri reservoir, showing deformed limestone layers and crushed rock material.

Fig. 5: Slickensides on fault surface (upper left above compass) indicative of dextral shear replacement.

The structural data of fault surfaces and the Slickensides located on them, measured with a structural compass at the southwestern edge of the reservoir, confirm the previously interpreted sinistral shear sense of a NE-SW striking strike slip fault (Fig. 6). This corresponds to the northern branch of the strike slip fault that traverses the reservoir area (fault in yellow). The southern branch of the strike slip fault was difficult to access and could only be reached via a steep creek bed. The dextral offset noted here at a low-quality outcrop is consistent with the shear sense previously determined from map material. However, the NW-SE strike of this fault (stippled in purple) differs from the previously determined NE-SW strike of the previous mentioned strike slip fault. The fault surface of the dextral foliation fault is also mineralized with carbonate minerals, indicating an extensional component and fluid transport. The different structural characteristics of the mineralization suggest repeated opening of the fault with associated carbonate mineralization.

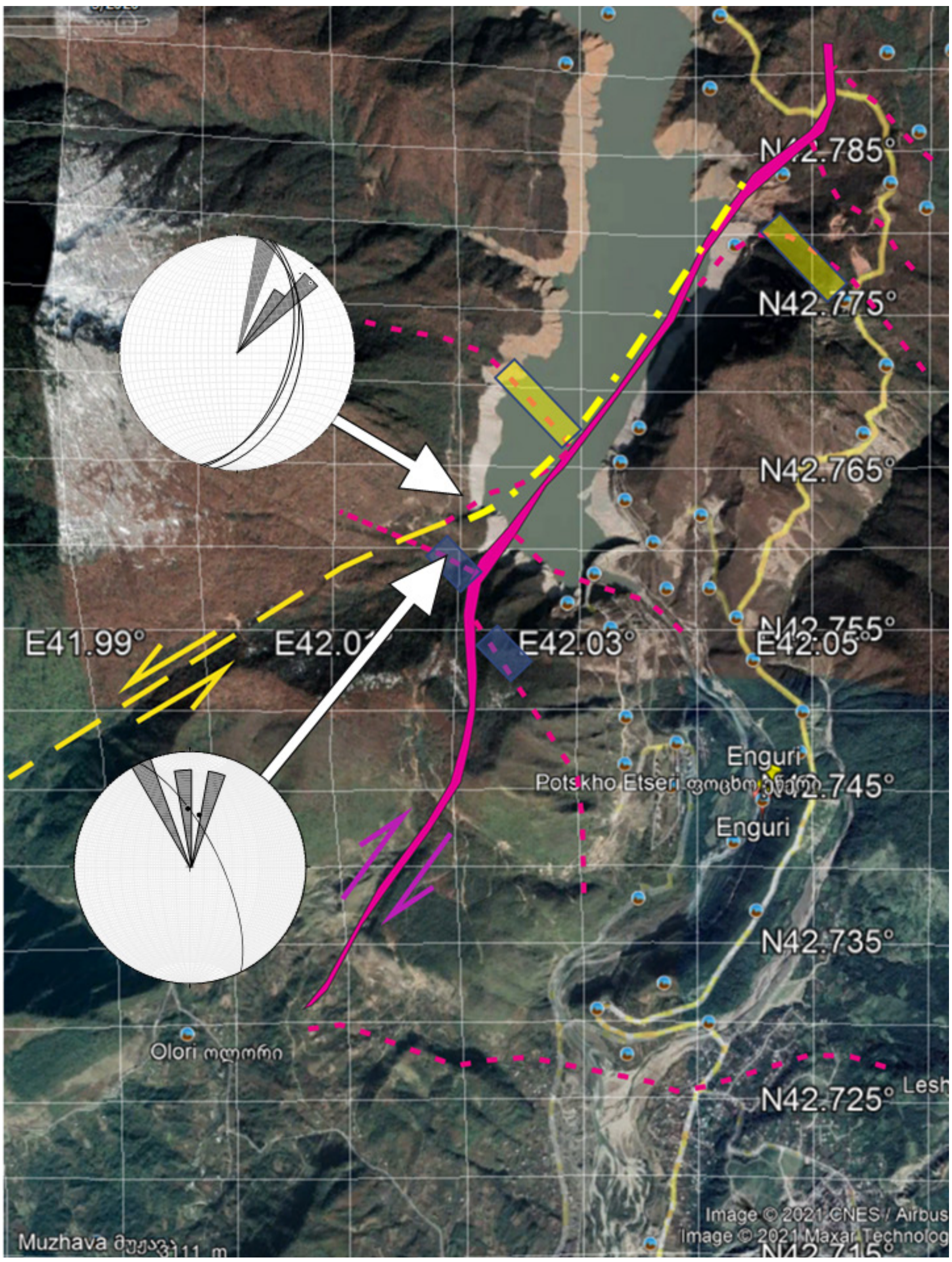


Fig 6: Interpretation of faults at Enguri Dam based on compiled data from old geologic maps. Compass measurements in the field are inserted.

Information from old Soviet Maps

The study area is located on the southern slope of the Caucasus. The immediate study area consists mainly of calcareous sediments. The stratigraphic sequence is complicated by small anticlinal and synclinal bends and by faults in individual.

The offset at the Ingirishi fault reaches an amount of up to one kilometer. Several other faults offset the study area into several thick blocks. These displacements, with complicated differential motions, have been occurring since the Pliocene. The base of the arch dam consists of calcareous series deposited in the Barremian. The rock sequence is divided into six units (Fig .7).

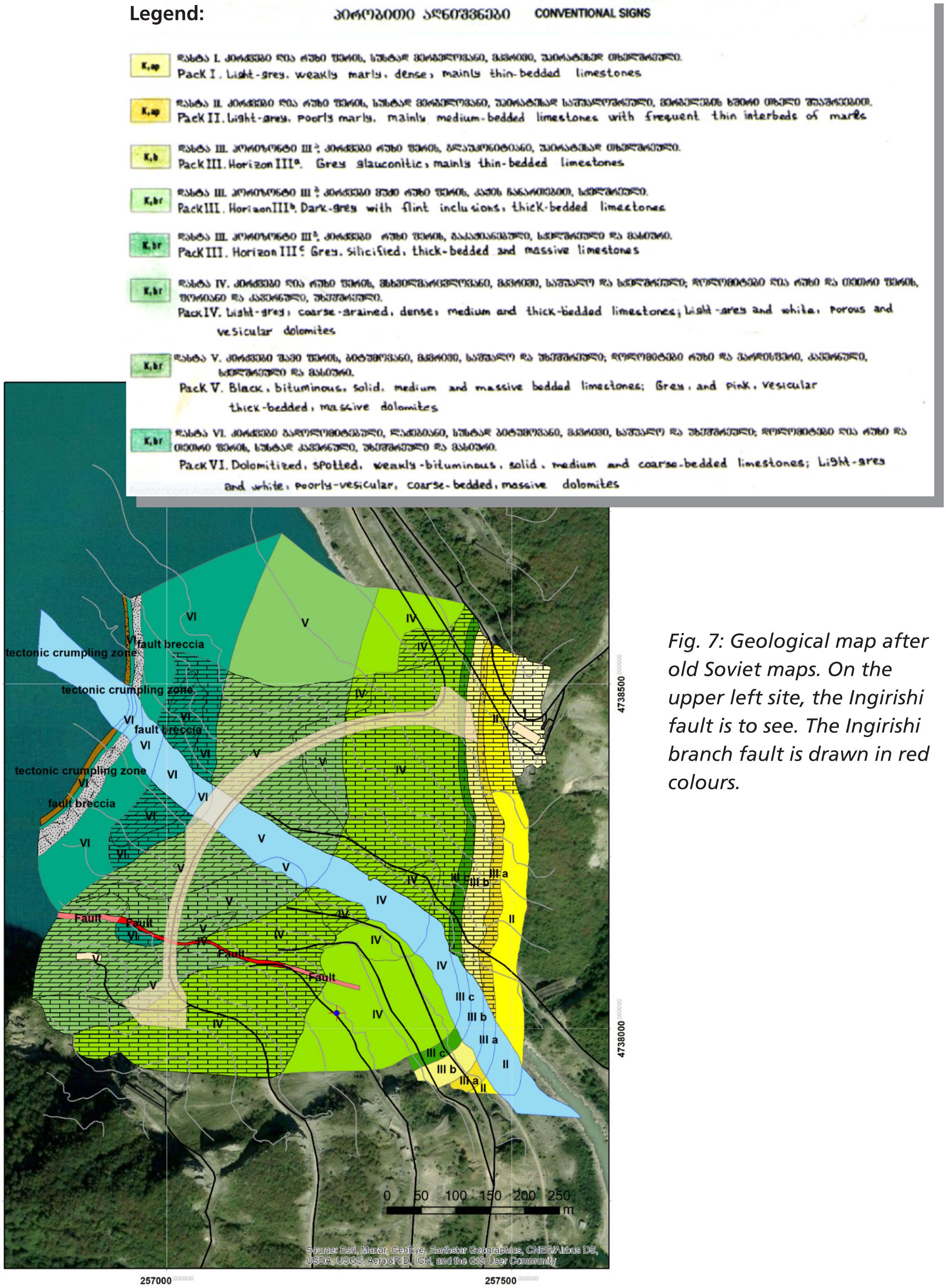


Fig. 7: Geological map after old Soviet maps. On the upper left site, the Ingirishi fault is to see. The Ingirishi branch fault is drawn in red colours.

Units 1 and 2 consist of limestones with low thickness and marl layers. Unit 3 consists of glauconitic limestones with flint concretions, Unit 4 - 5, located on the largest part of the study area, consist of intercalations of limestones and dolomites. Unit 6 consists of limestones and dolomitized limestones. In the dolomites of unit 6 are found in the upper part of the right bank, strongly calcified variants with reduced rigidity.
On the right side of the dam, the Ingirishi branch fault upthrust the northern part of rocks. Unit 4 rocks are encountered at the surface at the drilling point of the KIT 1 well. At depth, below the upthrust, the well meets the rocks of unit 5. These two units are mainly composed of limestones. At the KIT 2 drillsite also rocks of unit 4 were encountered, whereas in the nearby KIT 4 borehole rocks of Unit 3 consists of glauconitic limestones.

Enguri Dam History and Main Information

The Enguri Dam and Hydro Power Plant (HPP) sit at the top of the Enguri and Vardnili Cascade. The project includes one of the highest arch dams in the world, along with underground structures and substantial electro-mechanical works that provide 1,300 MW of power and an annual average of 4,000,000 MWh of energy for Georgia. The plant is a critical resource for the Georgian Power Grid. The project is owned and managed by LTD "Engurhesi", a state-owned company. The company also operates the downstream facilities at Vardnili 1, Vardnili 2, 3 and 4.
The construction of the HPP cascade was over decades and began in the early 1960s with completion and commissioning of the lower generating facilities, Vardnili 1, 2, 3 and 4 in the 1970s and the Enguri units coming online in the 1980s.

Key numbers:

- Height of Enguri Arch Dam: 271.5m;
- 15 km long and 9,5 m diameter Pressure Tunnel which diverts water from the Enguri Reservoir to the Enguri HPP;
- Underground Power Plant of Enguri consisting of five generating units each of 260 MW installed capacity with Francis turbines (total plant installed capacity – 1300 MW);
- Enguri main switchyard with five 500 kV unit transformers, 500 kV, 220 kV and 110 kV switchyards and connected overhead lines, serving Georgia's power system and connecting it with Russia's power system;
- Gali reservoir with the gravity dam of 60m height fed mainly by the tailrace tunnel from the Enguri HPP;
- Vardnili Power Plant with 220 MW installed capacity (three generating units of 73 MW each with Francis turbines);
- Water channel of Vardnili with over 500m³/s capacity taking water to the Black Sea along the 23 km open canal.
- Three smaller identical power plants on the channel with run-of-river Kaplan turbines, installed capacity of each plant is 40 MW with 2/20 MW generating units.

Fig. 8: Enguri Dam in Georgia and Power Plant in Abkhazia (Theresa Sabonis-Helf, HydroReview 2017)

Stop 1: Ground Based SAR (Westerhaus/Kutterer)

The Ground-based SAR (Synthetic Aperture Radar) is installed at the Warehouse for long-term deformation monitoring of Enguri dam. The system is composed of a yellow radar head with two antennas for transmitting and receiving the coherent electromagnetic signal at Ku-Band (17 GHz). The radar head moves on a 2 meters long linear scanner to virtually synthetise a large aperture which enables a higher resolution. The scanner determines the distance between the sensor and the backscatter points on the dam for all points on the dam with different range and cross-range position (cp. figure). Such, in continuous measurement mode the GBSAR provides a two-dimensional distance map – where each point of the map represents a different backscatter area on the dam – with very high precision every two minutes. By subtraction of these distance maps, the displacement for each point can be determined (= interferometric principle).
The white fridge-like cabinet controls the different parts of the device and the energy supply to the system. The GBSAR is protected from rain, wind and UV radiation by a shelter. A camera is also installed temporarily to monitor the weather conditions during the acquisitions. The system is completed by a router which sends the acquisition data to a server in near real-time.

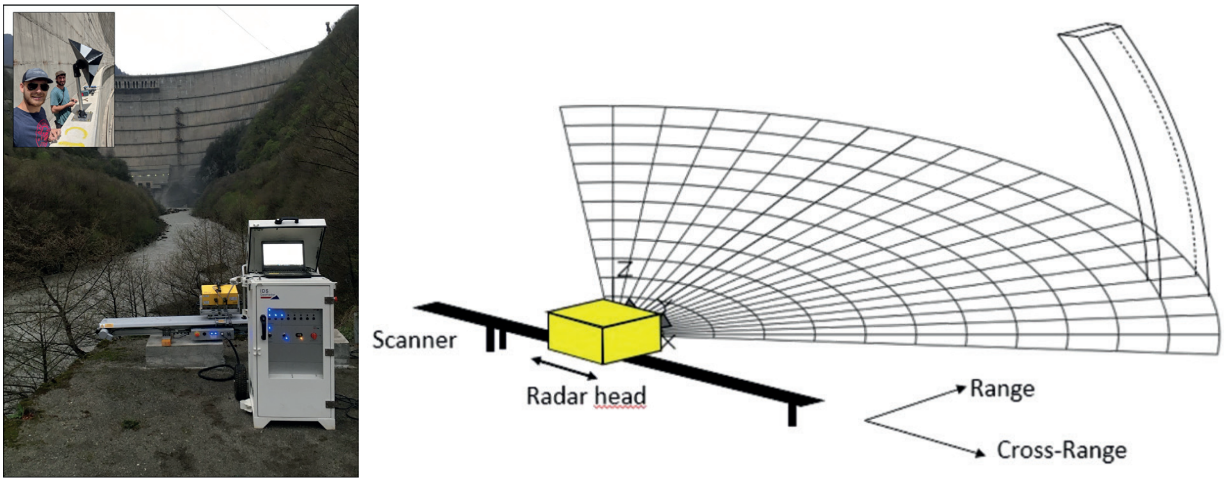


Fig. 9: In total 9 corner reflectors are installed on the dam, like the ones used for the satellite systems but smaller in dimension (see inset picture on left side above). As they are near the dam, the positioning of the reflectors with GNSS is not possible. That is why they were painted to recover their 3D position via photogrammetric techniques. Corner reflectors provide a strong and stable backscatter signal which can be located precisely and therefore can be used to reference the different radar images in a common system.

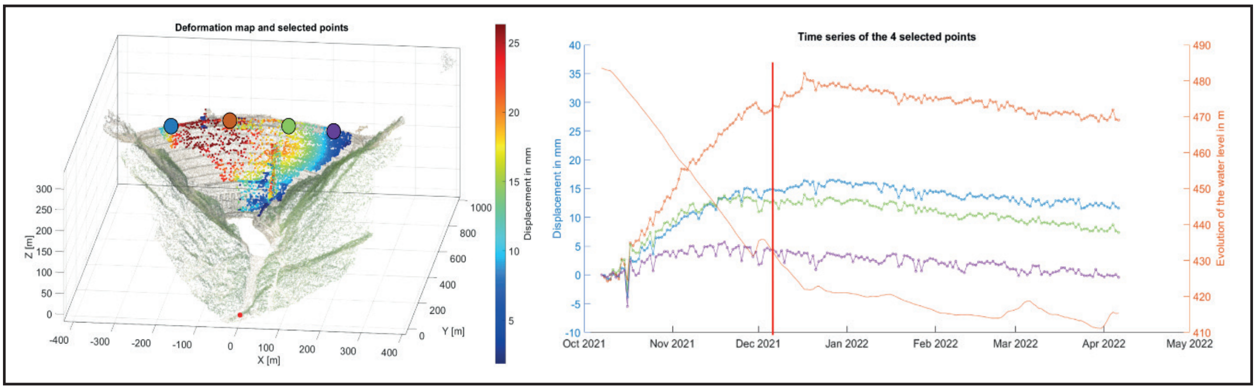


Fig. 10: Example of a deformation map (more precisely: displacement map) for the time period Oct-2021 to Apr-2022, retrieved from GBSAR observations of the dam (left). Several thousend points at the dam can be observed in parallel, which provides a detailed image of the dam motion. A time series can be presented for each of these points, as examplary shown here for four points on the dam crest.

Stop 2: Seismological Station at boreholes KIT-2 and KIT-4 (Tsereteli, Rietbrock, Gaucher)

In the framework of DAMAST (Dams and Seismicity) we deployed a dense high fidelity seismological real time network consisting of eight seismic broadband stations close to the dam structure. Particularly, high sensitivity detection capabilities is reached around Ingirishi fault segments. The network regional extent is completed with five surface stations in Nenskra region. We investigate the current state of seismicity at Enguri high dam area and Nenskra region in detail to study the possible relationship between the filling level of the reservoirs and seismicity.

Fig. 11: It takes full man and woman power to deploy the instruments and afterwards we were always very happy.

To lower the detection threshold by reducing the ambient background noise we installed four seismic stations in boreholes. From these KIT1 with a depth of ca. 250m is the deepest seismological station in Georgia. The remaining borehole stations are installed in 17-19 m depths. All stations are equipped with broadband sensors, Nanometrics Trillium compact posthole 20 s or MBB-2, Kinemetrics, while one offline short period sensor is installed in hydroelectric power plant building in Abkhazian territory, to increase the location accuracy of events occurring close to the Gali reservoir. At the site of KIT-2 and KIT-4 most modern DAS technology has been installed (first time in the Caucasus – as far as we know). We test this new equipment against the standard seismometers. It is foreseen to improve resolution and detection of events.

Until July 2022, more than 450 local events are detected, of which the location of 320 events fits into our area of interest. Ongoing seismicity monitoring of the area shows some local sources of seismicity (see Figure), however identification of active faults branches, geometry and slip mechanism and the response of seismicity to the dam reservoir water level change are subject of our ongoing study.

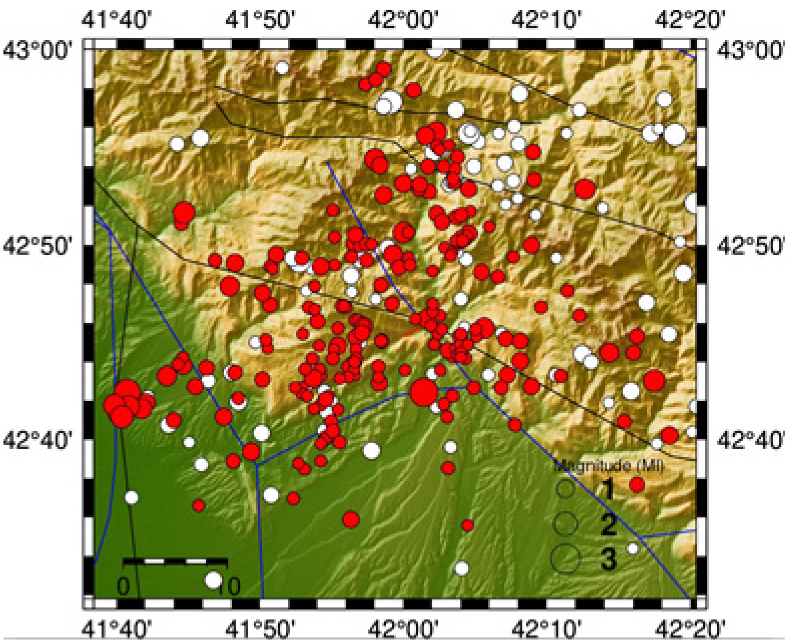


Fig. 12: Seismicity map obtained using the local seismic network currently operating at Enguri site. White circles represents the events that are poorly located (error greater than 5 km in at least one of hypocentral parameters). Scattered seismicity as well as clusters close to the fault lines are observed. The size of the circles are scaled base on events magnitude.

Stop 3: Geodetic station EAST, characteristics overview

The geodetic station EAST is coupled to an old massive concrete foundation and consists of a GNSS equipment for permanent use and a radar corner reflector.

The GNSS antenna is carried by a massive pillar monument which is made of two concentric arranged tubes with concrete inside the inner tube. The space between the tubes is filled by insulation material. The pillar itself is firmly connected to the old foundation by means of reinforcement steel and a stable concrete edging. The GNSS receiver is placed in a weatherproof cabinet. The energy requirements of the GNSS station are covered by a solar panel. A solar charge controller handles the energy flow to the two consumers, namely GNSS receiver and an LTE router, and two car batteries. Every 30 second, the GNSS equipment registers the signals of the currently available GPS and GLONASS satellites on one frequency. The observations are temporarily stored locally and are finally sent to a KIT server every 24 hours. This is done by the LTE router. The data are used to derive a time series of coordinates of the GNSS antenna in the accuracy of a few millimeters, revealing a possible movement of the GNSS station as a representative for the local deformation.

The radar corner reflector consists of three perforated aluminium plates arranged in an angle of 90 degrees to one another. This trihedral reflector is mounted on a vertical stand and aligned in the direction of the passing radar satellite in an ascending orbit, namely Sentinel-1. The stand is firmly connected to the concrete foundation by means of high-performance anchors. The reflector serves as a stable back-scatterer for the radar signals which is a desirable effect, leading into several advantages for the processing of the radar data. The phase center of the reflector can be accessed and thereby measured by terrestrial geodetic techniques to derive its coordinates. This is not possible for natural back-scatterers.

Fig. 13: Typical geodetic station with instruments and solar power panel

Lunch Break at Geodetic Station

Stop 4: KIT-Spartak well with overview on Jvari Reservoir

Within DAMAST and DAMAST-Transfer in total KIT has drilled the wells KIT-1 (222 m in 2020), KIT-2 (307 m in 2020), KIT-4 (70 m in 2020), KIT-Nenskra (278 m in 2021), KIT-Spartak (> 220 m in 2022) and several shallower wells.

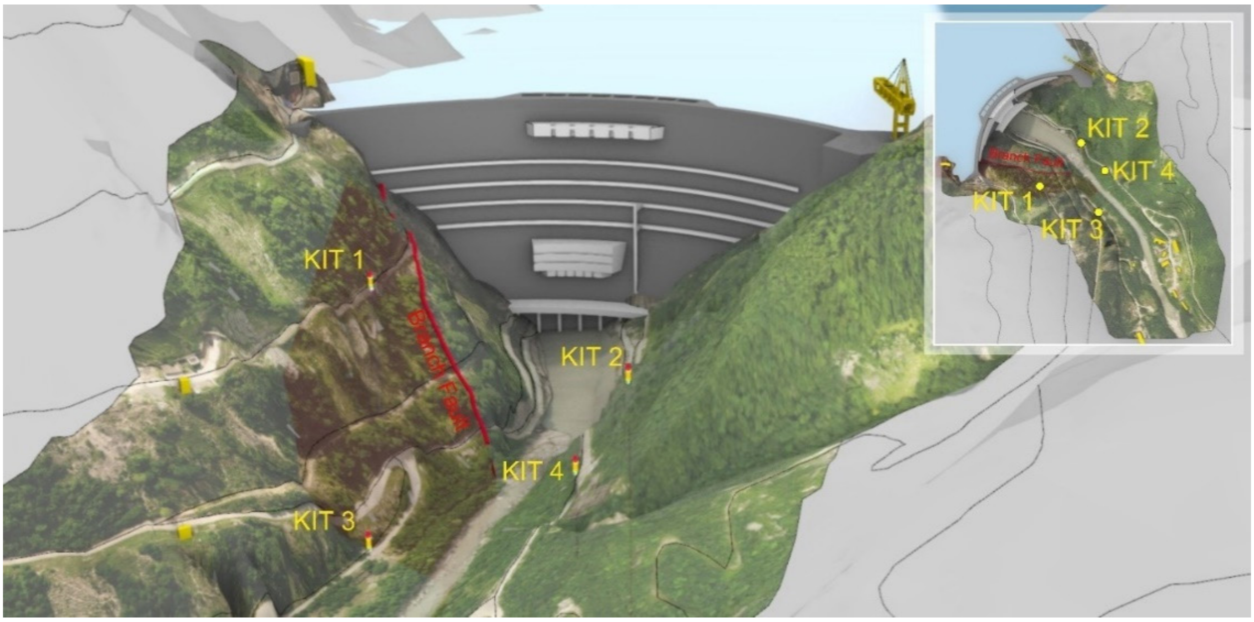


Fig. 14: Overview on locations of deeper wells drilled wiethin DAMAST, the location of WELL KIT-Spartak in on the left bank of the Enguri.

All deep wells (and some of the shallow wells too) have been logged with most modern logging equipment to determine the state of stress and to inspect the condition of the rock around Enguri Dam and in Nenskra valley. The modern logging tools use optical and acoustical methods.

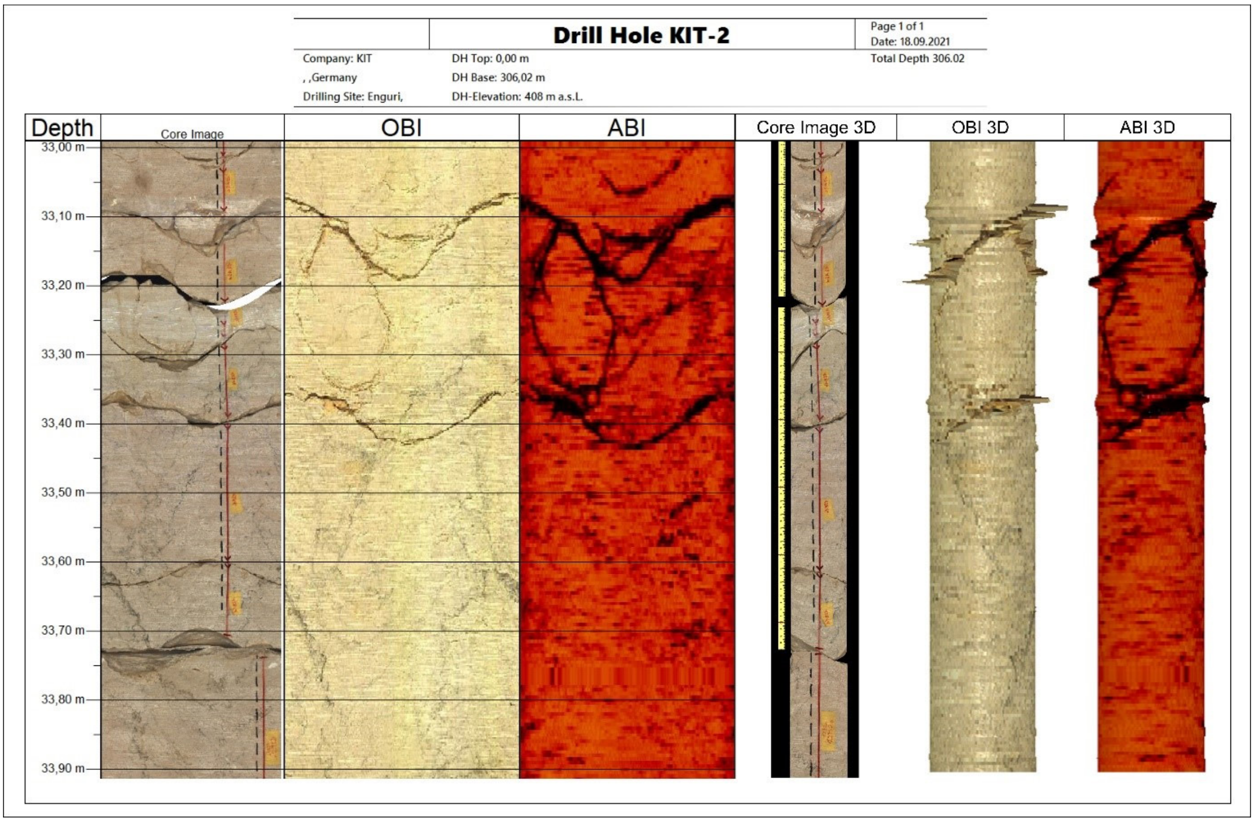


Fig. 15: Example of a logging section with optical and acoustical televiewer for which also drill cores are available. Some fractures within the cores are also visible in the loggings. This enables to orient the core.

Major Results:

1. Identification of Fault zone on the right bank

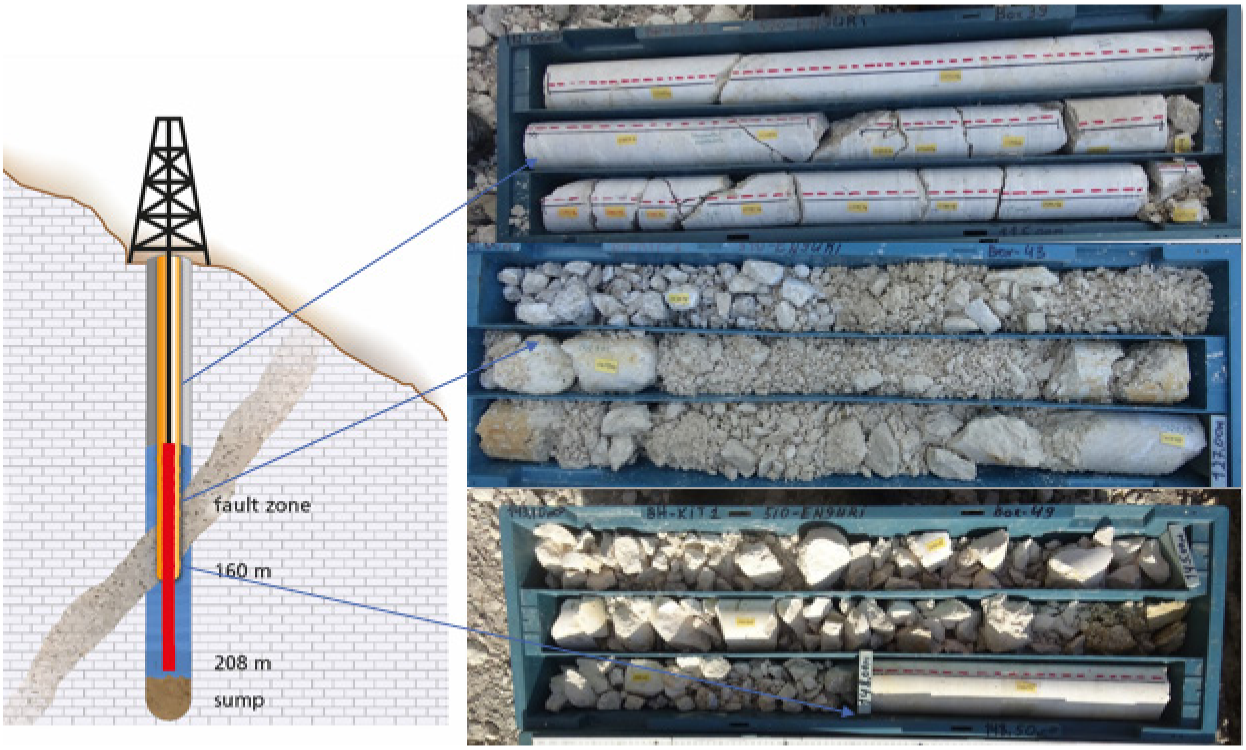
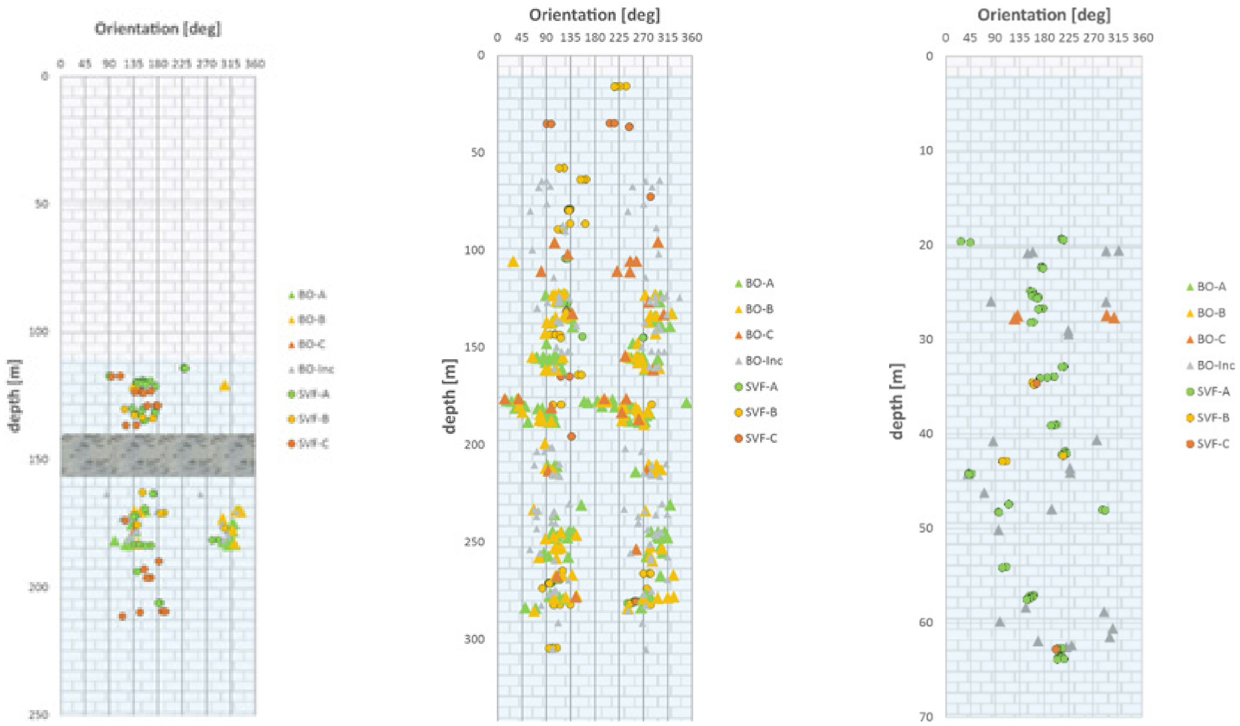


Fig. 16: Sketch of well KIT-1 which successfully crossed the branch fault which crosses the right side dam abutment.

2. Stress Field Orientation based on hundreds of pieces of analysed drill cores and breakouts and fractures identified in borehole logging



Borehole KIT-1 with fault zone Borehole KIT-2 Borehole KIT-4

Fig. 17: Stress orientations with depth for 3 deep wells at Enguri dam.

3. Numerical Model of Stress Situation at Enguri Dam

For a better understanding of the stress field and the spatial distribution, a 3D numerical FE model was created. This model was calibrated on the field observations of the two deep boreholes KIT-1 and KIT-2. The model showed that the stress field in the area of the Enguri dam is mainly determined by topographic stresses.

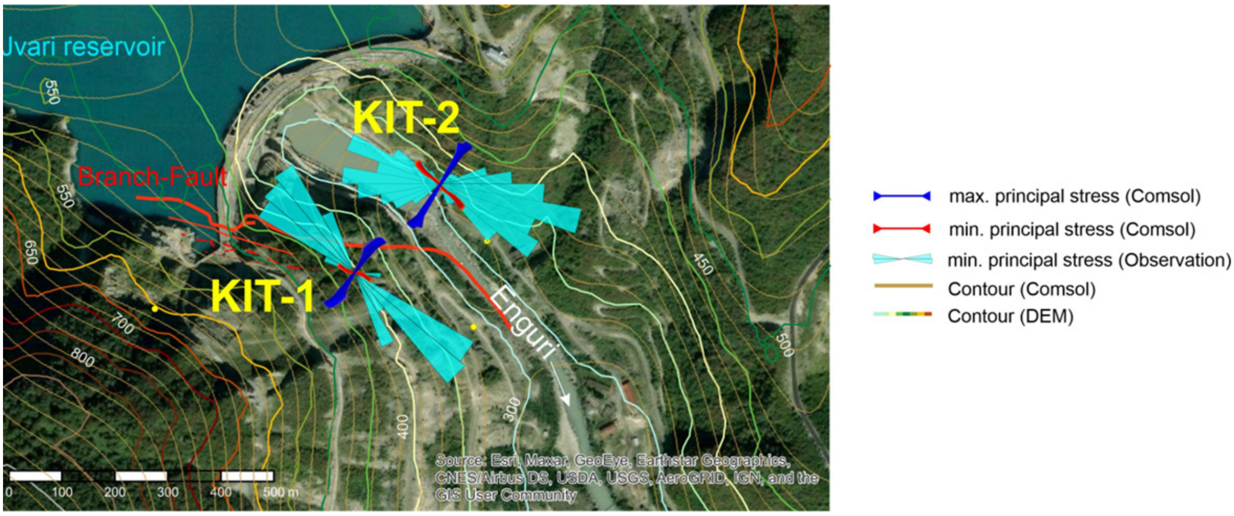


Fig. 18: Modelled principal stresses in comparison with stress observations in wells KIT-1 and KIT-2 show a good match (max. principal stress has to be perpendicular to min. principal stress orientation)

4. Interpretation of Causes of Leakage of Power Tunnel

These findings were applied to the power tunnel, where a one-sided opening of the construction joint was observed at the position 13.7 km. The orientation of the maximum stress is perpendicular to the tunnel. The 2D numerical FE model shows tangential tensile stresses in the area of the downslope construction joint. Under operation, these are even reinforced by the water pressure, so that an opening of the joint is supported.

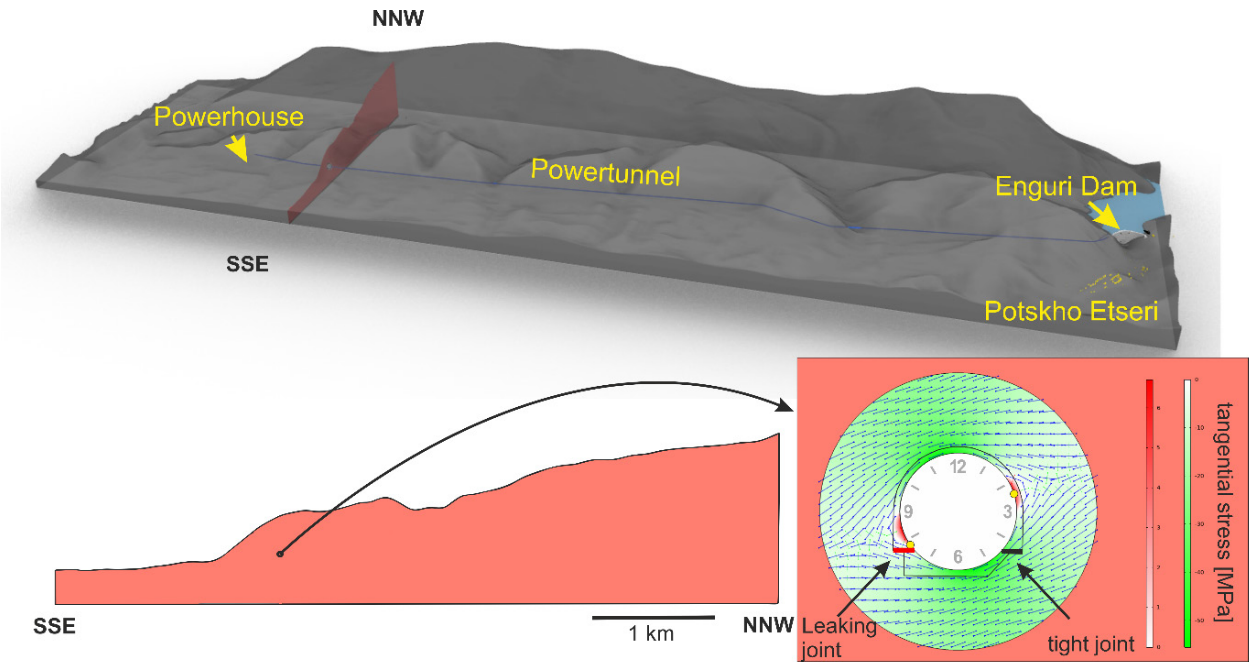


Fig. 19: Numerical model of stress field confirms that the left construction joint is in an area of tensile stresses and thus most likely to be open.

Stop 5: Overview Platform near the directors building of Engurhesi Ltd. With explanations about the building of the dam by Director Mebonia and Director Chania.

Here you get first hand information about the history of the dam, the time of its construction, its current role in the Georgian Power Supply.

Stop 6: Boat Ride Jvari Reservoir (Kron/Hilgert)

Like all large dams, the Jvari Reservoir is threatened in the medium to long term in its operational safety and stability by increasing sedimentation of the reservoir. Sediment that was transported through the Enguri River to the Black Sea before the construction of the dam is now retained in the reservoir and leads to a reduction of the reservoir volume. In order to be able to record the extent of the sedimentation, extensive measurement campaigns were carried out in 2019 and 2021 with the objectives:

1. the repeated survey of the reservoir volume and morphology for the calculation of mass displacements in the lake
2. the exploration of sediment stratification and sediment composition in the different sections of the reservoir
3. the measurement of vertical water quality profiles for the detection of density currents in the reservoir
4. recording sediment texture and grading curve of sediments by free-fall penetrometer (graviprobe) at 16 points along the longitudinal axis of the Jvari reservoir
5. derivation of the total amount of sediment in the lake and the delivery rates from the Enguri and Neskra catchment
6. to create a profound database for modelling of the future behaviour of the reservoir and to create operational opportunities

The current accumulated sediment volume in the reservoir is about 220 million m³. In the vicinity of the dam, sediments with a thickness of approx. 70 m have been detected and have meanwhile reached the height of the bottom outlets of the dam. These outlets are of great importance for the operation of the dam, as it ensures that the reservoir can be emptied in case of emergency. In order to maintain this functionality, elaborate flushing campaigns have to be carried out on a regular basis, which, however, are only effective in a locally narrowly area and only for short periods of time. In the medium term, further sedimentation will lead to the height of the sediment front reaching the inlets to the hydropower plant. The fine sediments introduced will lead to abrasion of the turbine blades.

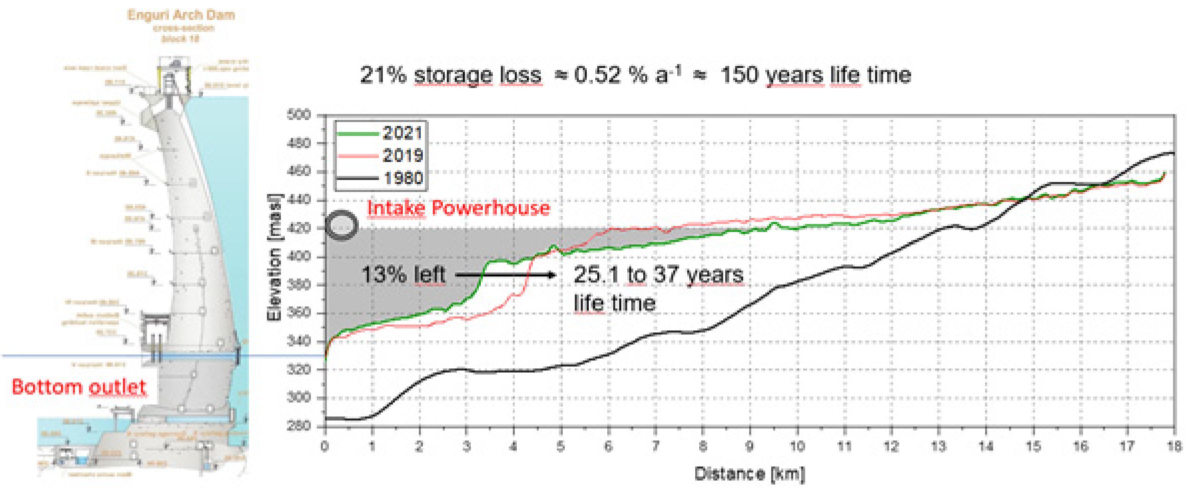


Fig. 20: Cross section of Enguri dam and change of sediment distribution between the measurement in 2019 and 2021.

Stop 7: Return to Hotel for Dinner and Evening tour inside Enguri Dam