The SUSTAMINING Project –

Towards Optimisation of Natural Stone Extraction

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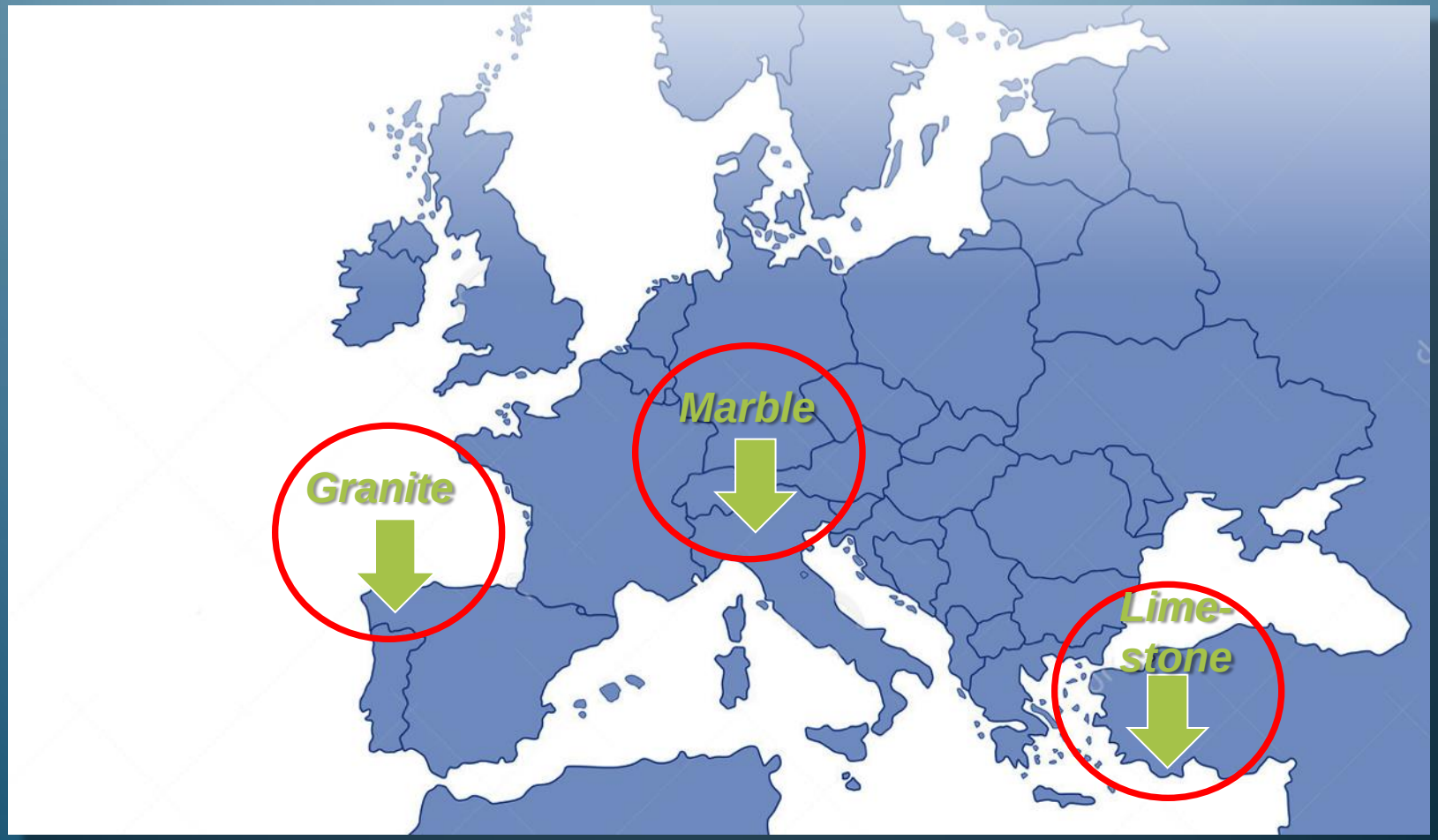
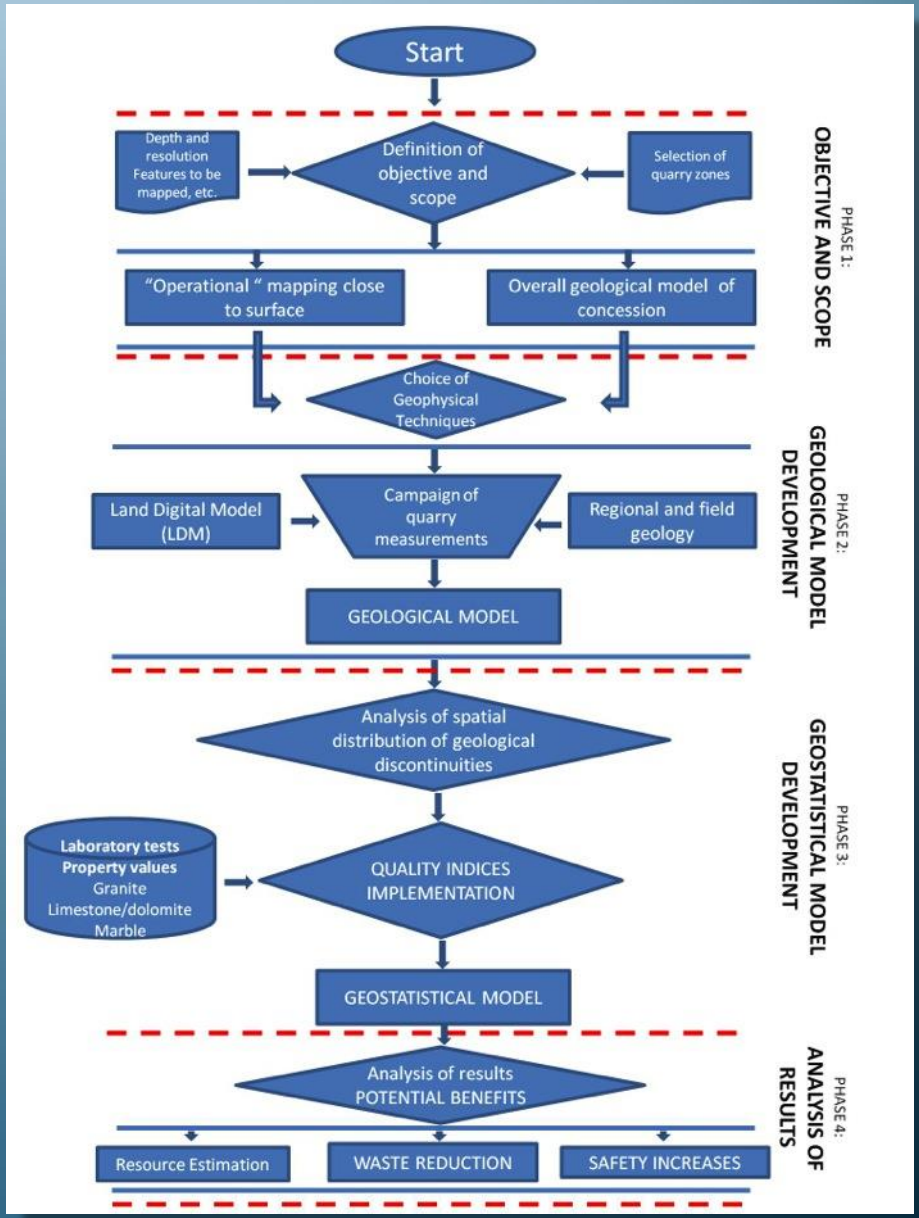
OBJECTIVES

- The project aimed to contribute to the vision of an invisible, zero-impact quarry
- The natural stone extraction sector, still is seen as being old-fashioned and causing a variety of environmental impacts
- The project objectives were to
  - Develop new methods for the selective exploitation according to demand, taking into account the quality requirements
  - Assess in the field by non-destructive geophysical methods the 3D-distribution of resources of varying quality
  - Optimise resources estimation, quarry-planning and extraction on the basis of quality data using geostatistical methods

PROJECT TEST SITES IN SPAIN, ITALY, AND TURKEY



WORK-FLOW TOWARDS OPTIMISED EXTRACTION

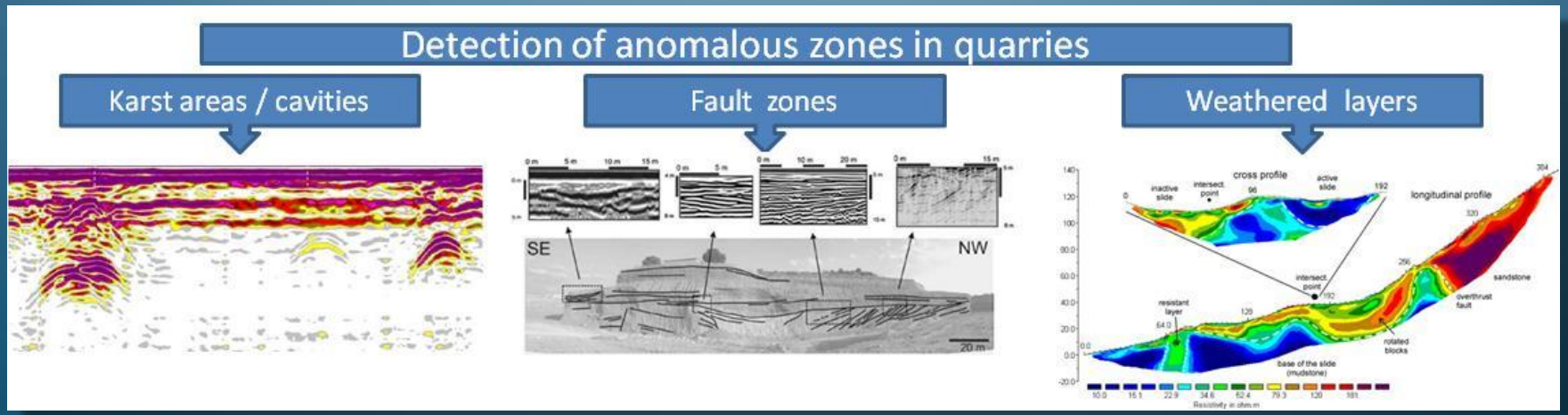


STEPS IN PROJECT EXECUTION

- Collation of historic data to scope and target methods
- Development of a Digital Elevation Model (DEM) of the quarry using geo-referenced LiDAR
- Non-intrusive field investigations using geophysical methods such as Electrical Resistance Tomography (ERT), Ground Penetrating Radar (GPR), and hammer seismic (reflexive/refractive)
- Laboratory testing of stone samples to calibrate geophysics and to establish range of stone qualities
- Geostatistical treatment of all data to develop a comprehensive 3D-site model
- Providing 3D-maps of rock qualities according pre-selected indices

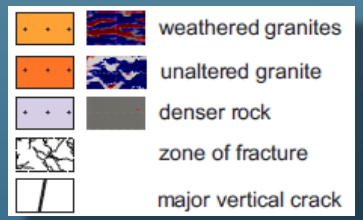
OBJECTIVES OF FIELD GEOPHYSICS

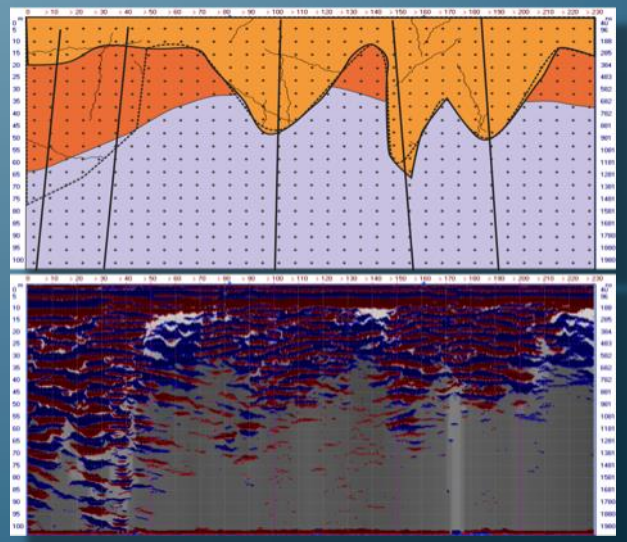
- The geophysical techniques used in the SUSTAMINING project allow to detect in quarries various types of undesirable features:
  - Faults / fractures
  - Cavities / karst
  - Weathered layers
  - Overburden thicknes



GPR – GROUND-PENETRATING RADAR

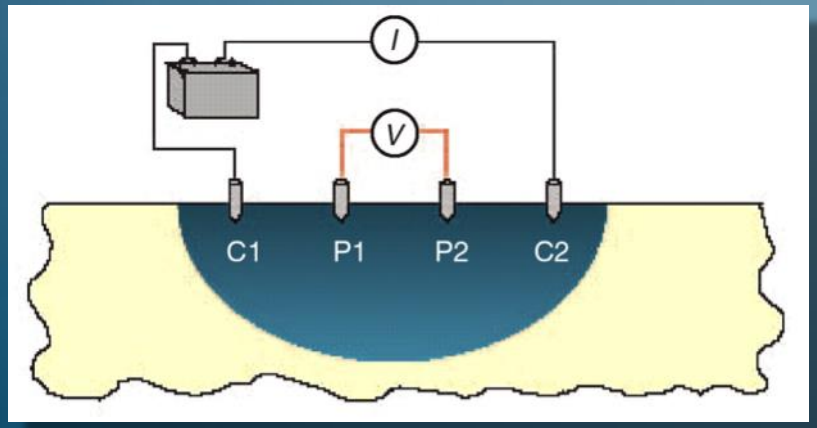
- GPR is based on the classical principles of a radar-location.
- It consists of transmitting and receiving antennae, a data capturing and recording unit, and a control unit.
- The transmitter emits very short electromagnetic pulses that are reflected from internal surfaces in the geological body
- Depth of sounding and resolution in space depend on the pulse length and frequency used, the amount of energy transmitted, and the sampling frequency of the detector

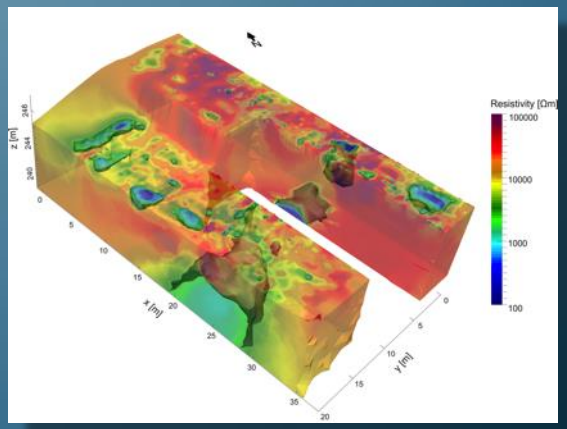




ERT – Electrical Resistance Tomography

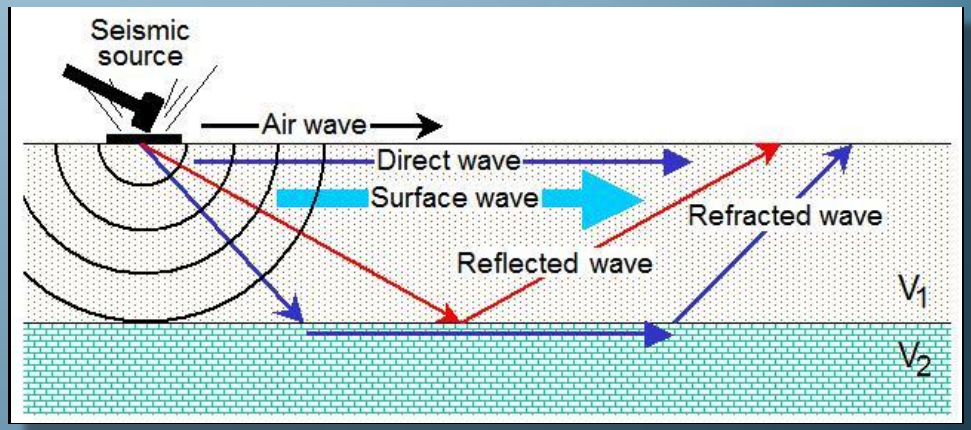
- A series of four-point electrical resistance measurements are made
- A current is injected between electrodes C1-C2 and the potential is measured between electrodes P1-P2
- Profiles are measured by laying out a row of electrodes and making successively other pairs are used as electrodes C1-C2 and P1-P2 respectively
- The measured potential patterns need to be numerically 'inverted' in order to calculate resistivity distribution pattern

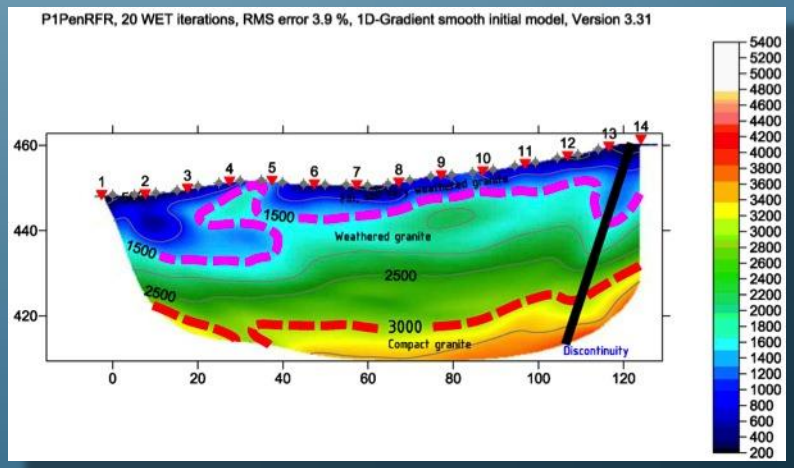




HAMMER SEISMIC (reflective / refractive)

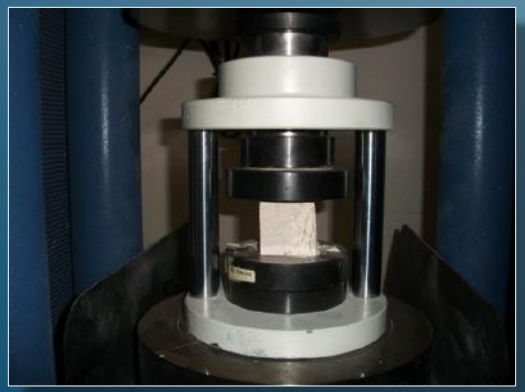
- Seismic waves generated by a hammer or a drop-weight are reflected and refracted at internal surfaces in the rocks
- Run-times and amplitudes of waves allow conclusions on the depth of internal surfaces and density/elasticity contrasts





LABORATORY CHARACTERISATION OF STONE SAMPLES

- Samples are characterised with the purpose of assessing their quality and to provide for ground-truthing data for the geophysical surveys
- The following parameters have been determined:
  - EN 12407 Petrographic examination.
  - EN 13161 Flexural strength.
  - EN 1926 Compressive strength.
  - EN 1936 Apparent density and open porosity.
  - EN 12371 Frost resistance.
  - EN 14146 Modulus of elasticity



STONE QUALITY INDICES

- A matrix of stone quality indices was developed to guide the extraction process
- Based on the laboratory determinations quality indices were assigned
- Using the results from the geophysical mapping, areas of similar quality can be delineated

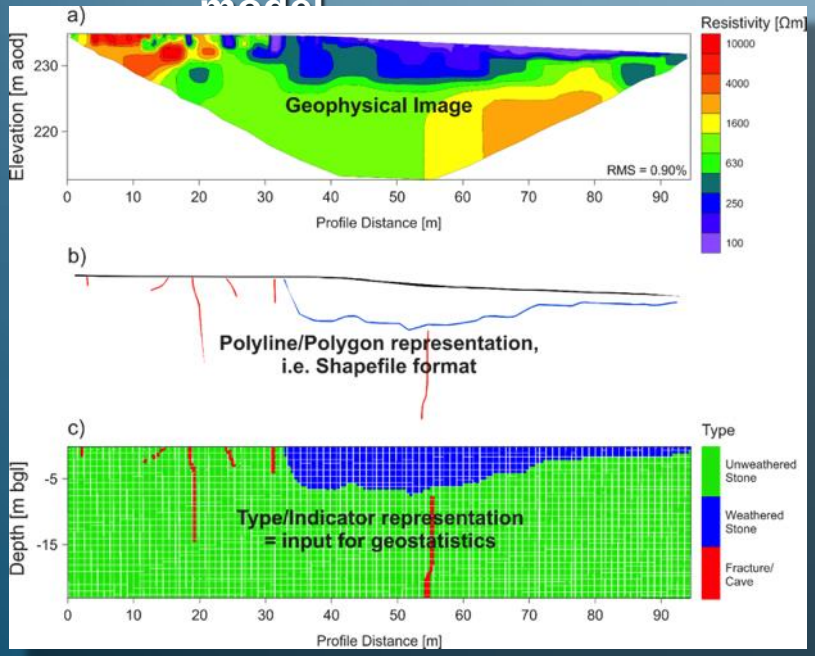
STONE VARIETY	QUALITY FOR QUARRYING	PROPERTY VALUES		
		External applications	Internal applications	No suitable
G	C1 C2 C3 C4	E	I	X
L				
M				

- G, L, and M stand for granite, limestone, and marble respectively
- C1 to C4 describe the density of faults etc. within a block of marketable size

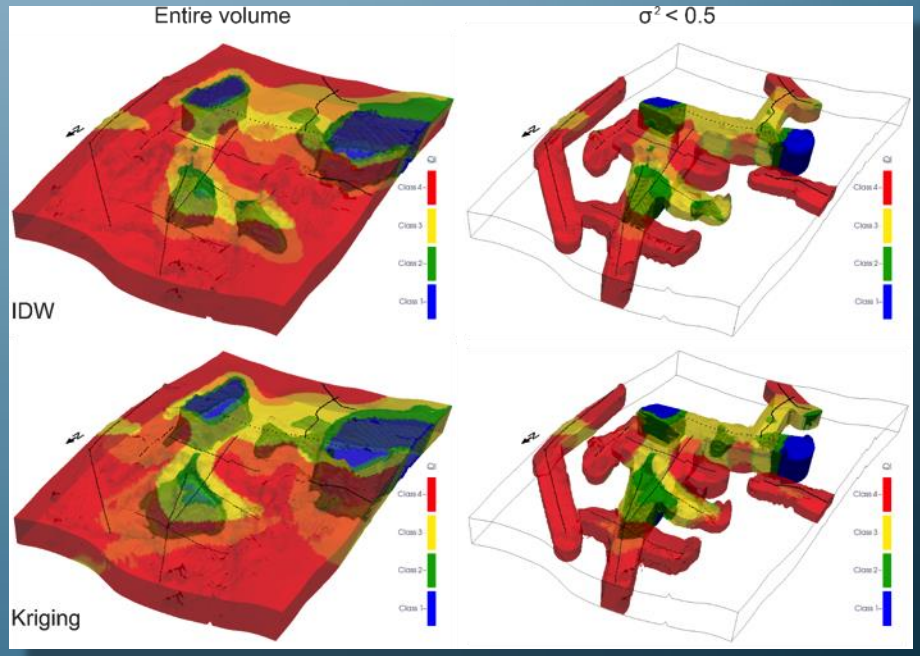
GEOSTATISTICAL EVALUATION OF INVESTIGATIONS

- The data from the geophysical field-work and the laboratory test were collated in a Geographical Information System (GIS) and subject to geostatistical modelling

Data transformation model

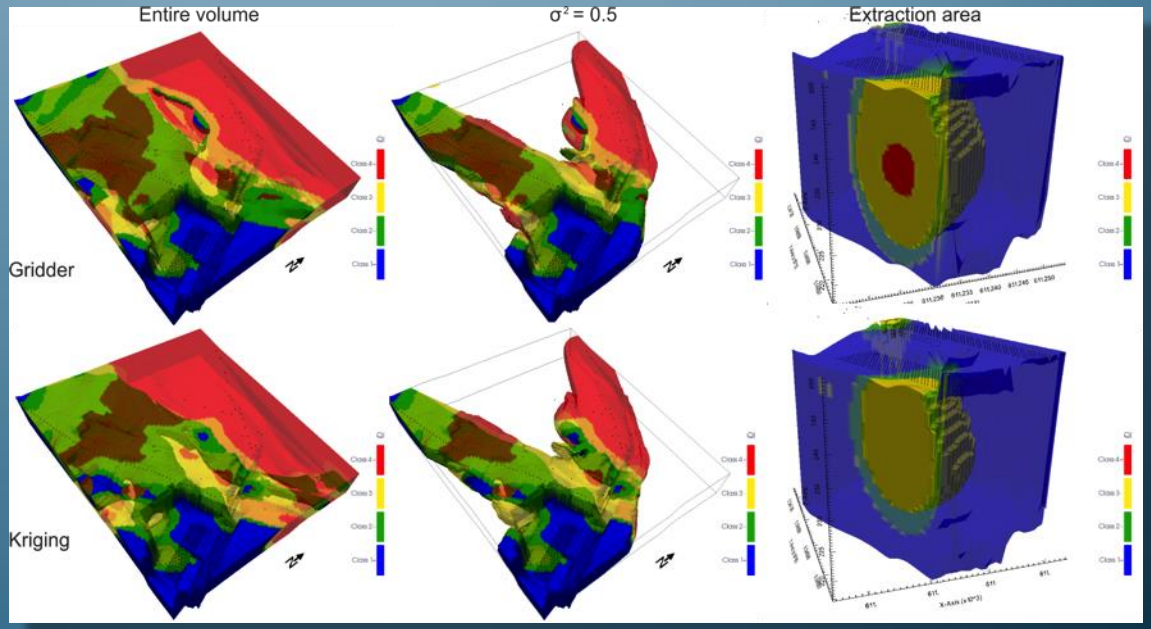


Example of geostatistical



RESOURCE AND RESERVE ESTIMATES

- Using the Quality Indices together with geostatistical modelling allows to estimate and spatially delineate the resources and reserves of a given quality
- This model the allows to guide extraction and to plan for the life-time of the quarry
- Predictive quality modelling reduces the amount of unwanted extraction and waste produced



CONCLUSIONS

- The methodology developed within the project SUSTAMINING allows a detailed assessment of resources and reserves of a (future) quarry
- It is based mainly on non-invasive field investigations combined with geostatistical modelling
- The method will guide the efficient exploitation of a quarry
- It results in the targeted extraction of stones of a desired quality and minimises unwanted extraction and waste
- Reduced material flows in the quarry improve its sustainability

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