UNIVERSITÀ
DEGLI STUDI
DI TRIESTE

Applied seismology

Seismic site selection

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Seismic station site selection and preparation crucial network issues.

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Introduction

I would concentrate on some issues important for quality of seismic data acquisition in weak motion as well as strong motion field and show that not only seismic

equipment quality

but also

system engineering, site selection, preparation, and system maintaining

are crucial for data quality.

What is high quality seismic recording?

The term high quality seismic data acquisition encompasses several aspects which are to some extent specific for seismology as a typical non experimental science:

1.

We usually want to record as many as possible events. Thus **high detectability** (efficiency of seismic installation in term of quantity of recorded data) is desired.

2.

For many seismicity studies and/or time dependant process studies one wants continuous, stable recording performance (in time and in space). Thus **completeness of data** sets (reliability of operation, stable sensitivity, adequate spatial coverage) is desired.

3.

One wants to record true ground motion, free of instrumentally generated and other artifacts. Thus **high fidelity** of recording of ground motion during earthquakes is desired.

4.

One should record signals which are relevant to the goal of recording. Thus **representativness** of data with respect to this goal must be assured. For example: for general seismicity studies bedrock motion should be measured and local site effects and soil structure interaction are artifacts, for local site effects studies, structures and soil-structure interaction site selection and preparation is different.

What limits us today?

To what extent all these aspects are adequately covered depends on signal recording

technology

AND

system design, seismic station sites selection, and preparation.

Today, generally speaking, recording technology fulfills 95% of all needs, although not all instrumental problems have been solved yet. The quality of recording at the most state-of-the-art installations is limited by

seismic station site conditions.

Not so in the past. Surprisingly, in seismological community the awareness of this fact is all but strong. Many new installations work in a sub-optimal conditions because selection and/or preparation of seismic sites was inadequate. People pay too little attention to it, or most of the funds have already been spent on "boxes" before it was adequately addressed.

Re:1 – detectability

Most of contemporary equipment fulfills any desire. Consequently, detectability is limited with seismic noise at most of the continuously operated seismic stations and at all stations operated in stand alone triggered mode. This is even true for the best modern strong motion sensors at most sites.

Quality of seismic recording in terms of detectability is thus a matter of seismic site selection and preparation and not of the equipment.

Sensors tested:

Wilcoxon X731B
PMD MET (new)
Streckeisen STS-2
Endevco 86
MEMS SF1500A
Kinemetrics EPISENSOR
Wilcoxon 9XL
RefTek 131-02

M 7, 190km depth at 85 deg

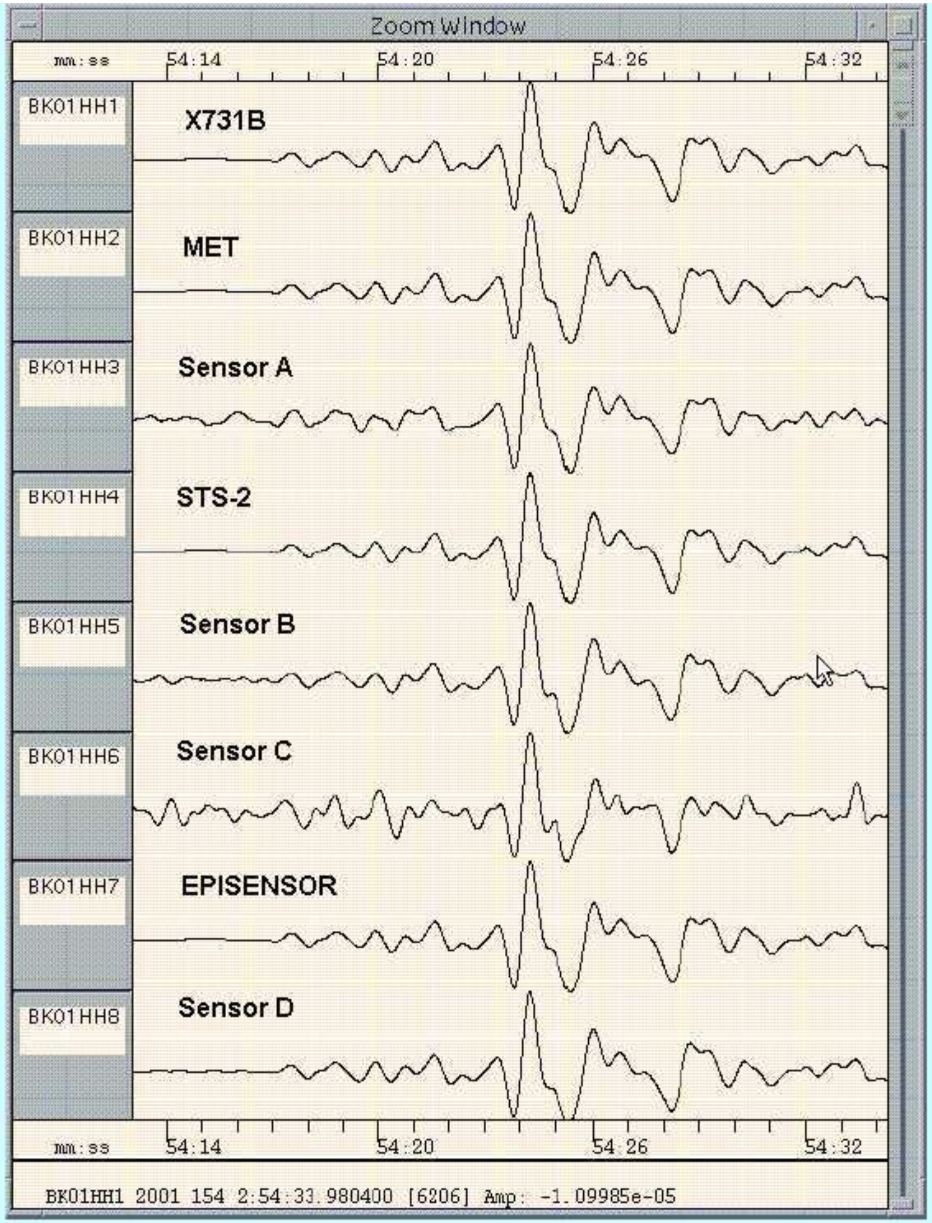
0.3 - 2 Hz band pass filtered
P-P octave RMS is about
2e-5 m/s^2

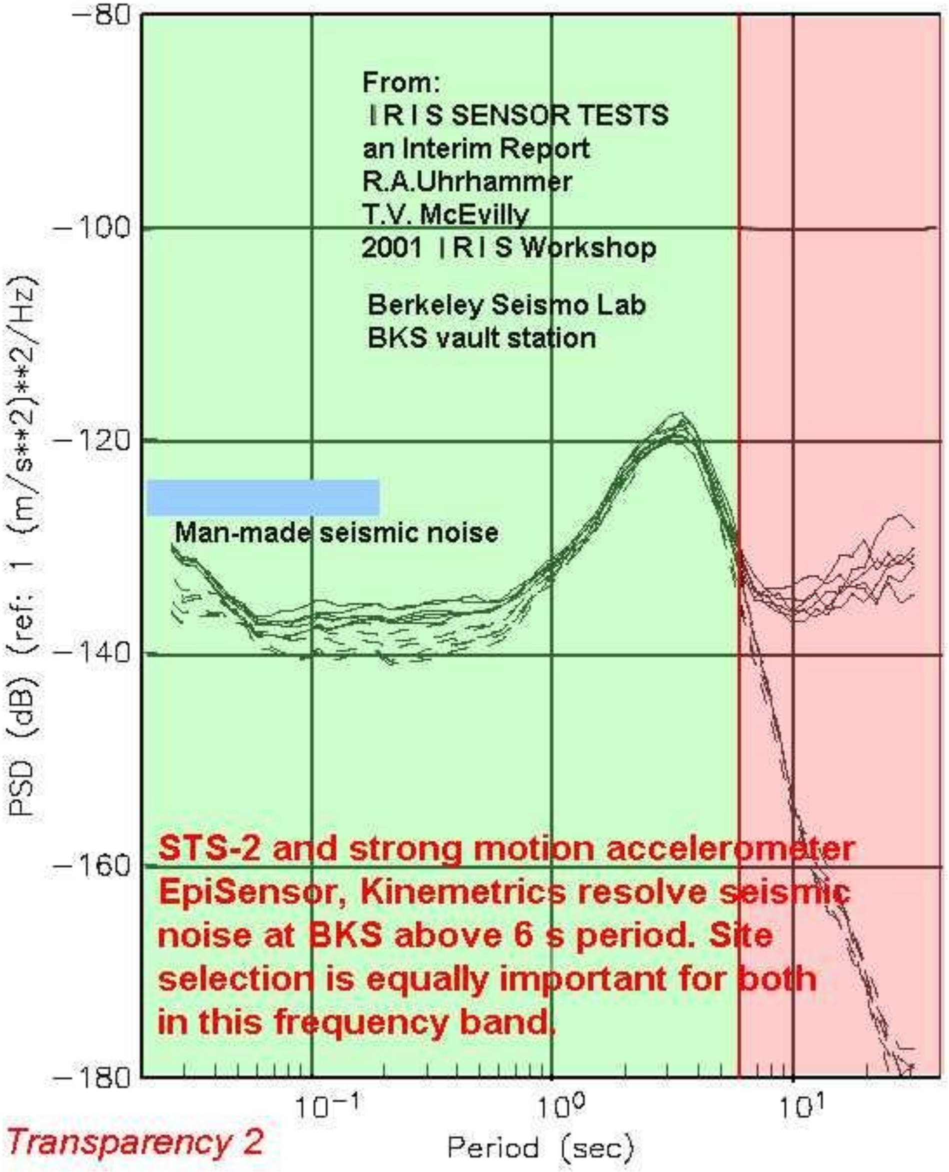
From:
IRIS SENSOR TEST
an Interim Report
R.A.Uhrhamer and T.V.McEvilly

2001 IRIS Workshop

Widely different sensors produce comparable records.

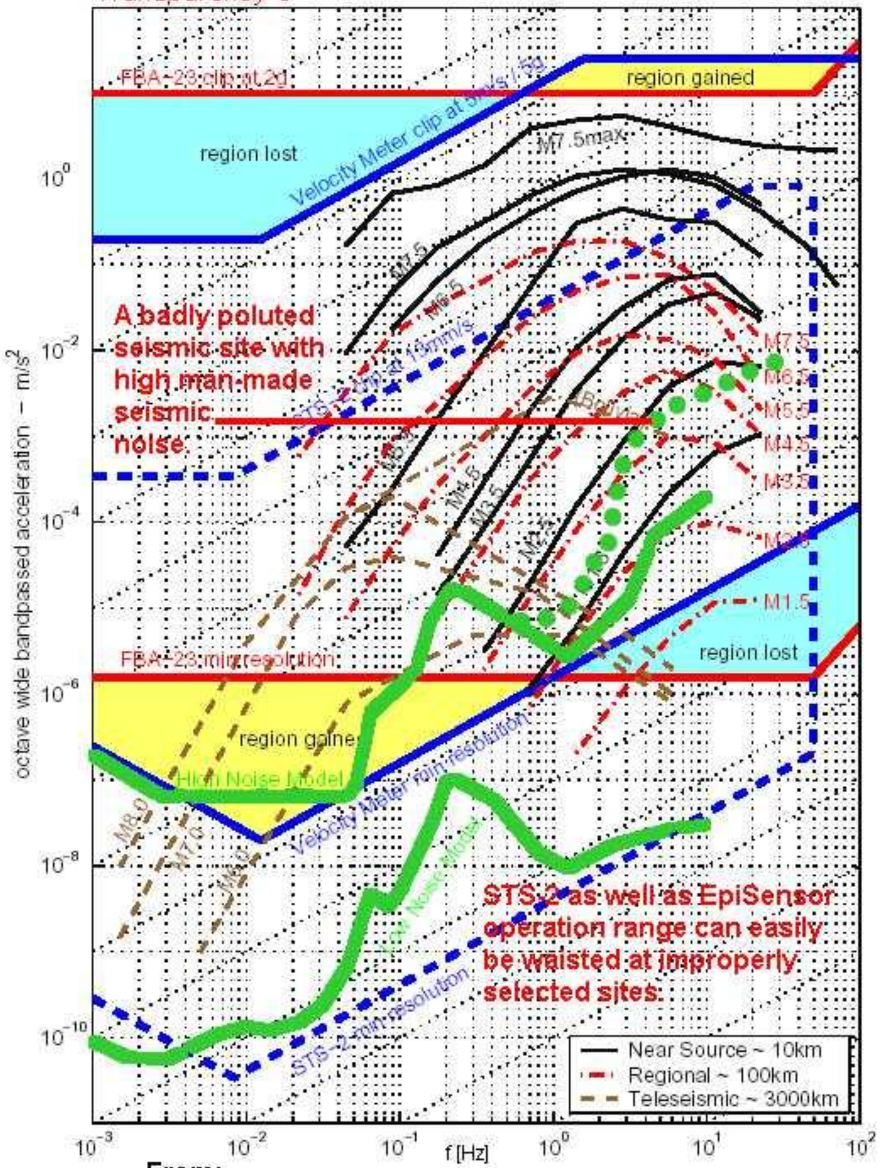
Transparency 1





Transparency 2

Transparency 3



From:

Potential Advantages of a Strong Motion Velocity Meter as Opposed to a Strong Motion Accelerometer by John F. Clinton, Thomas H. Heaton

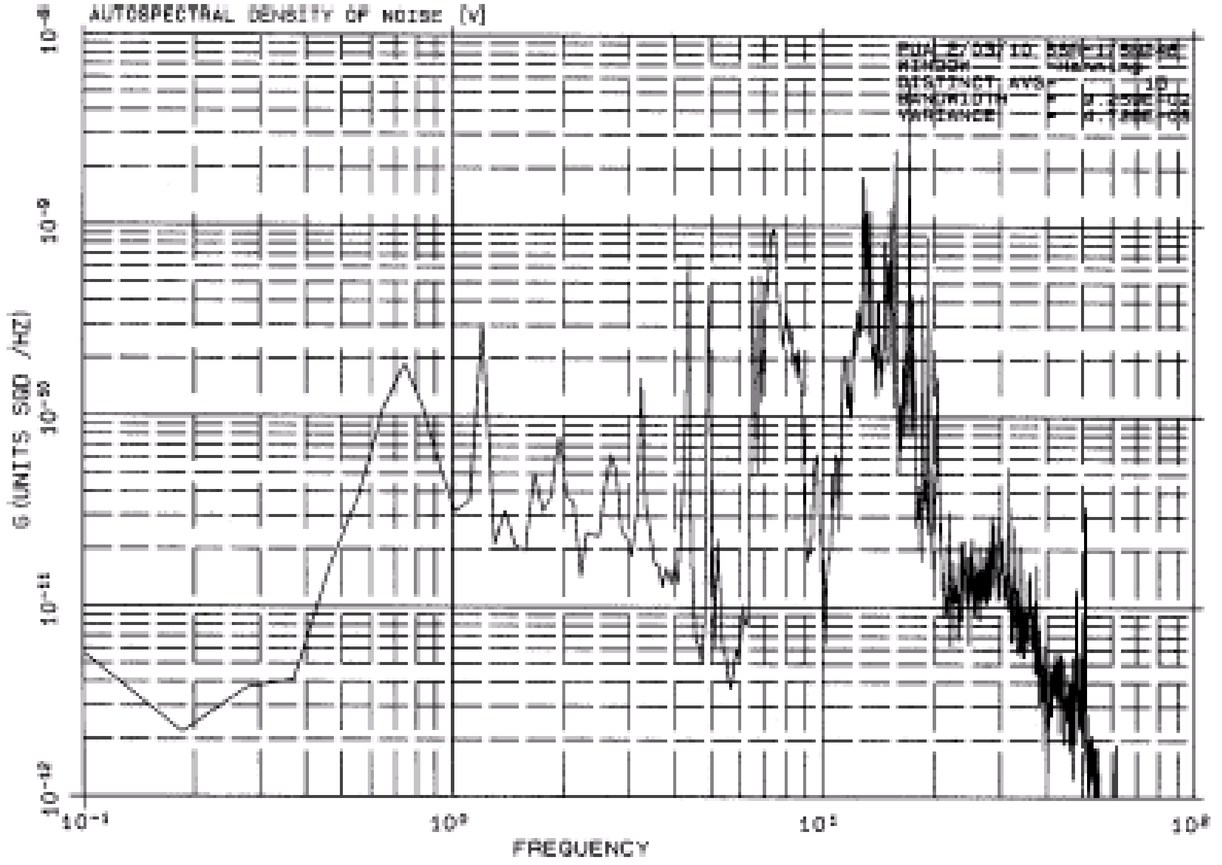


Fig. 7.7 Typical seismic noise spectrum (ground velocity power density in $m^2/s^2/Hz$) at a potential seismic station site showing man-made seismic noise generated by a nearby city and heavy machinery working in a 4 km distant quarry.

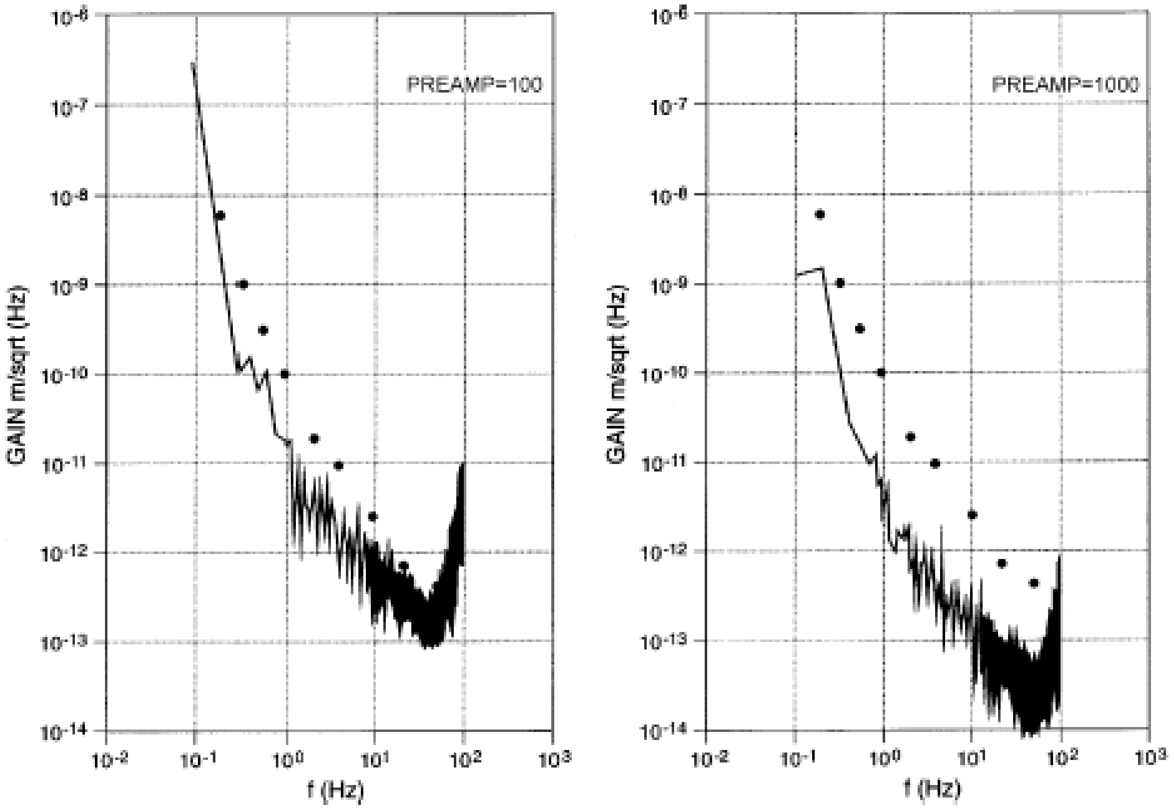


Fig. 7.12 Comparison of the average values (•) of the ground displacement spectrum of the seismic noise recorded at the quietest site found during a noise survey in NW Iran with the equivalent displacement spectrum of the combined instrumental self-noise of the Kinemetrics SS-1 seismometer and SSR-1 data logger at a pre-amplification level of 100 times (left) and 1000 times (right), respectively. Note that one order of magnitude difference in the amplitude spectra corresponds to 20 dB difference in the respective power spectra. Only the higher pre-amplification allows the resolution conditions to be met at the quietest sites in the area under investigation.

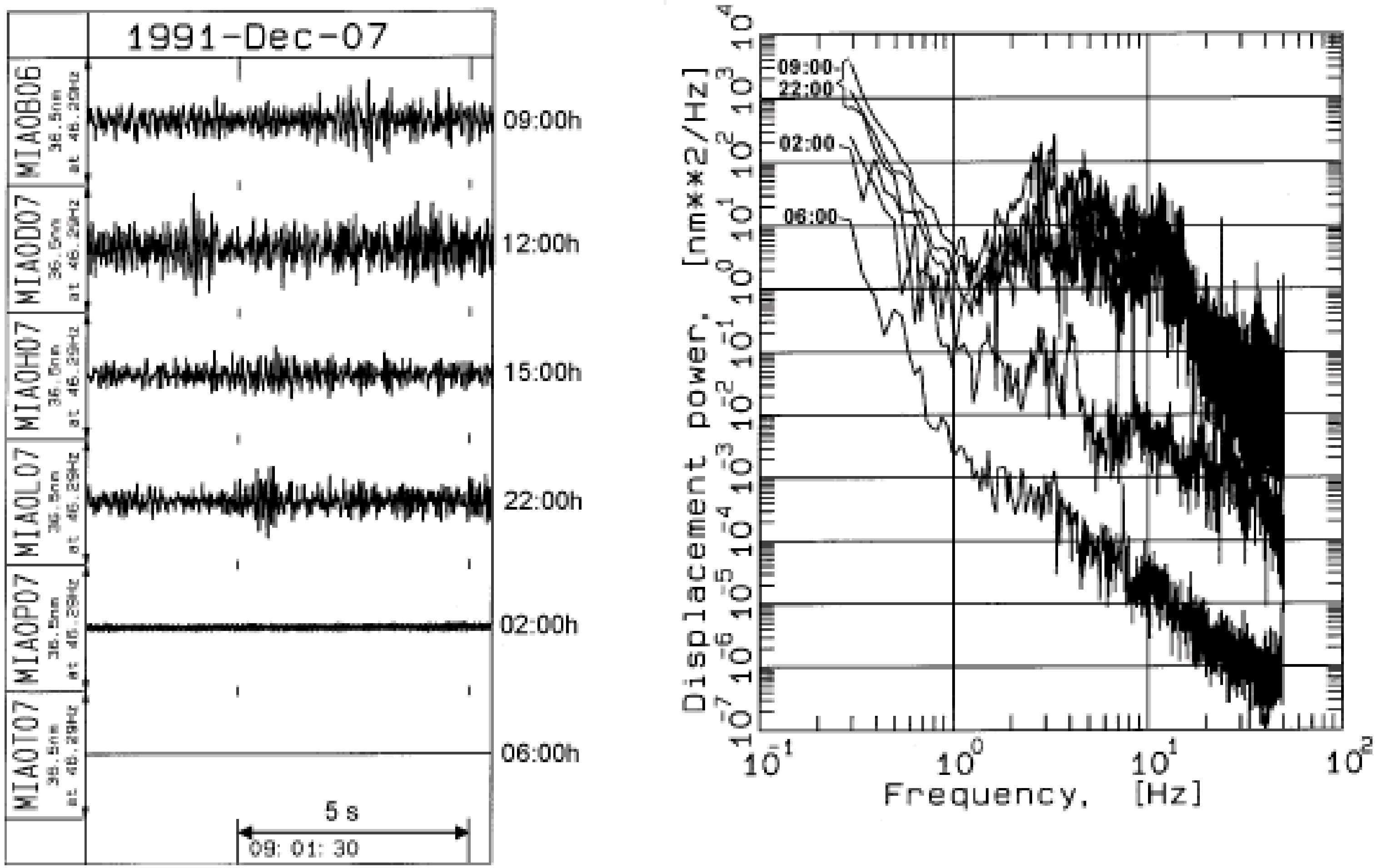


Fig. 7.15 Comparison of relatively quiet sections of vertical component noise records (left; without strong transients) and related power spectra (right) at a reference site in a town in NW Iran. The measurements were made at different times of the day.

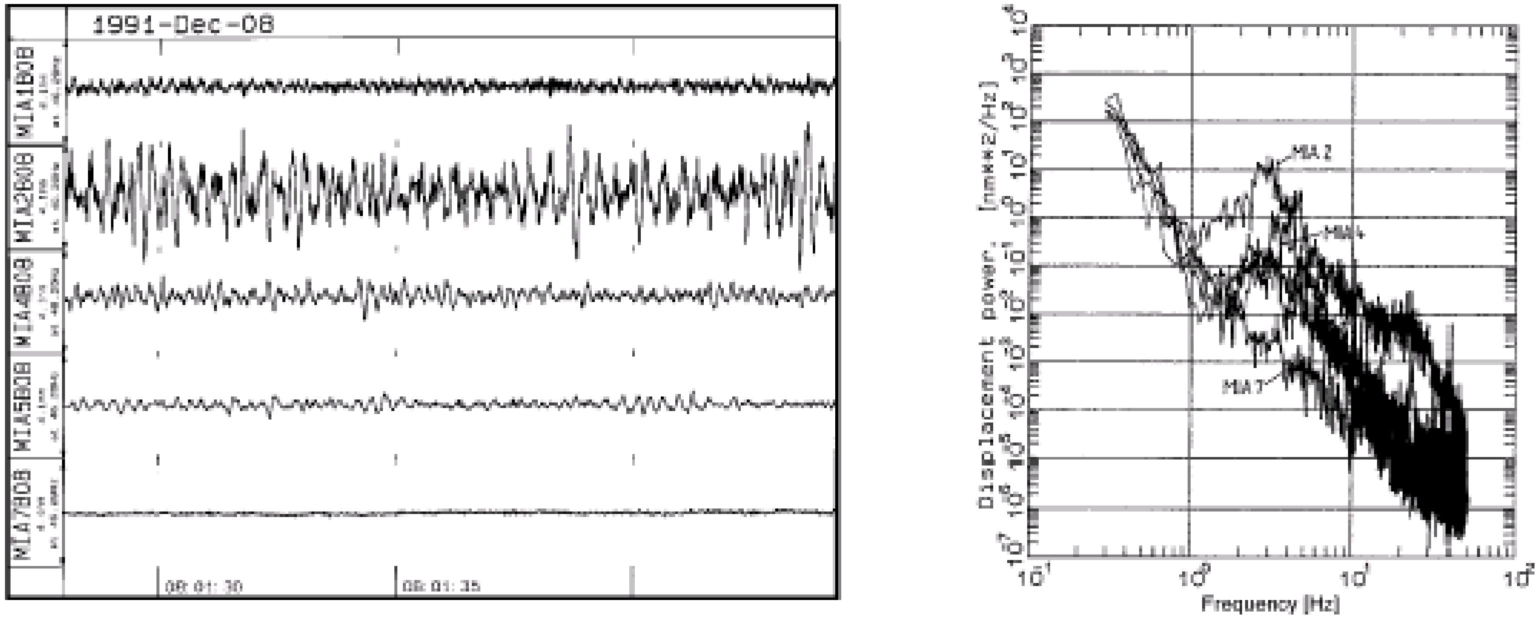


Fig. 7.16 Noise recordings (left) and related power spectra (right) at different sites in NW Iran. From top to bottom: 1.) Unconsolidated Miocene terrace, 2.) Unconsolidated Alluvial valley fill, about 2 km away from the main road, 3.) as for 2.) but some 5 km away from main road; 4.) outcropping volcanic hard rock near the road in a valley (with no nearby traffic at the time of measurement, 5.) Volcanic hard rock surface) near a mountain pass road. The noise at MIA 7 is around 1 Hz very close to the global New Low Noise Model (see sub-chapter 4.1) and at 10 Hz only about 14 dB above it.

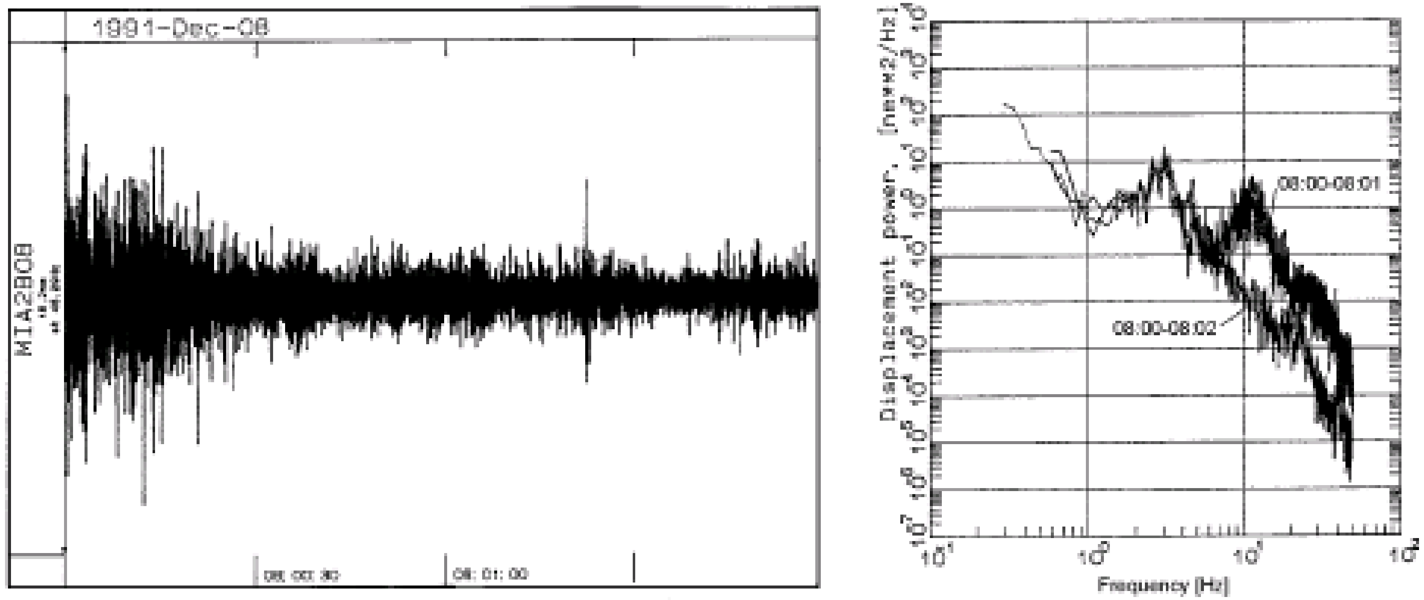


Fig.7.17 Noise record and related spectra for the first minute (transient) and second minute (background noise). The transient is due to a truck passing by at several 100 m distance from the recording site.

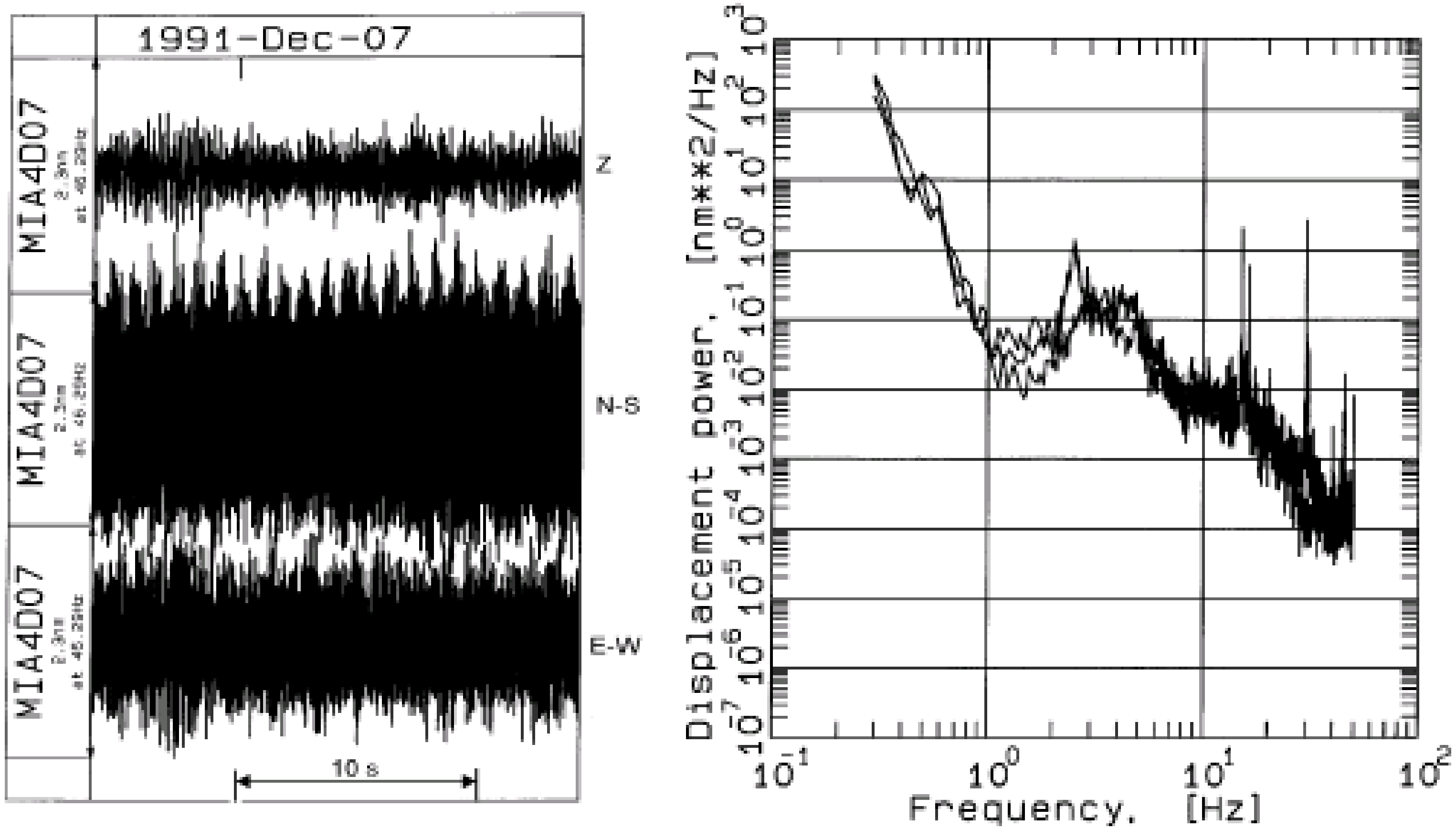


Fig. 7.19 Noise records and related power spectra near to a transformer house and power line. Note the monochromatic spectral lines around 13, 30 and 50-60 Hz, either induced by the AC current frequency and its lower harmonics and/or caused by the vibration of the transformer.

Re: 2 - completeness of data set

Completeness of data set is a matter of combined issues:

a) equipment reliability by itself,
b) network planning (proper selection of network geometry) and selection of seismic sites,
c) site preparation, and
d) network operation.

a) Equipment reliability

Practice shows that two most frequent reasons of technical failures of seismic stations and networks are:

- Data communication link failures (too frequently it happens that too unreliable communication links were selected to be used in a new network) and

- Battery failures (particularly during strong events and their aftershock sequences, when main power fails for a longer period of time).

b) network planning

The most reliable equipment will not perform, if station sites are positioned in an inappropriate network geometry resulting in poor event location within 'blind spots.

c) site preparation

Potential lightning damages due to an inadequate protection, water intrusion and vandalism considerations must be treated adequately

d) network operation

Regular maintaining should be based on a philosophy "act before something fails". Sufficient spare parts and technical personnel promptly available must be available in case of technical failures.

Re: 3 – fidelity of ground motion recording

This aspect is mainly a matter of technology (can be corrupted by instrumental reasons, insufficient resolution and/or dynamic range, instrumental noise, nonlinearities, clipping, higher harmonics, intermodulation effects, rectification effects, drift, and/or by other non-instrumental reasons like excessive seismic noise). Today 24 bits recording, oversampling principle, and force feedback type sensors assure excellent fidelity. However even thou:

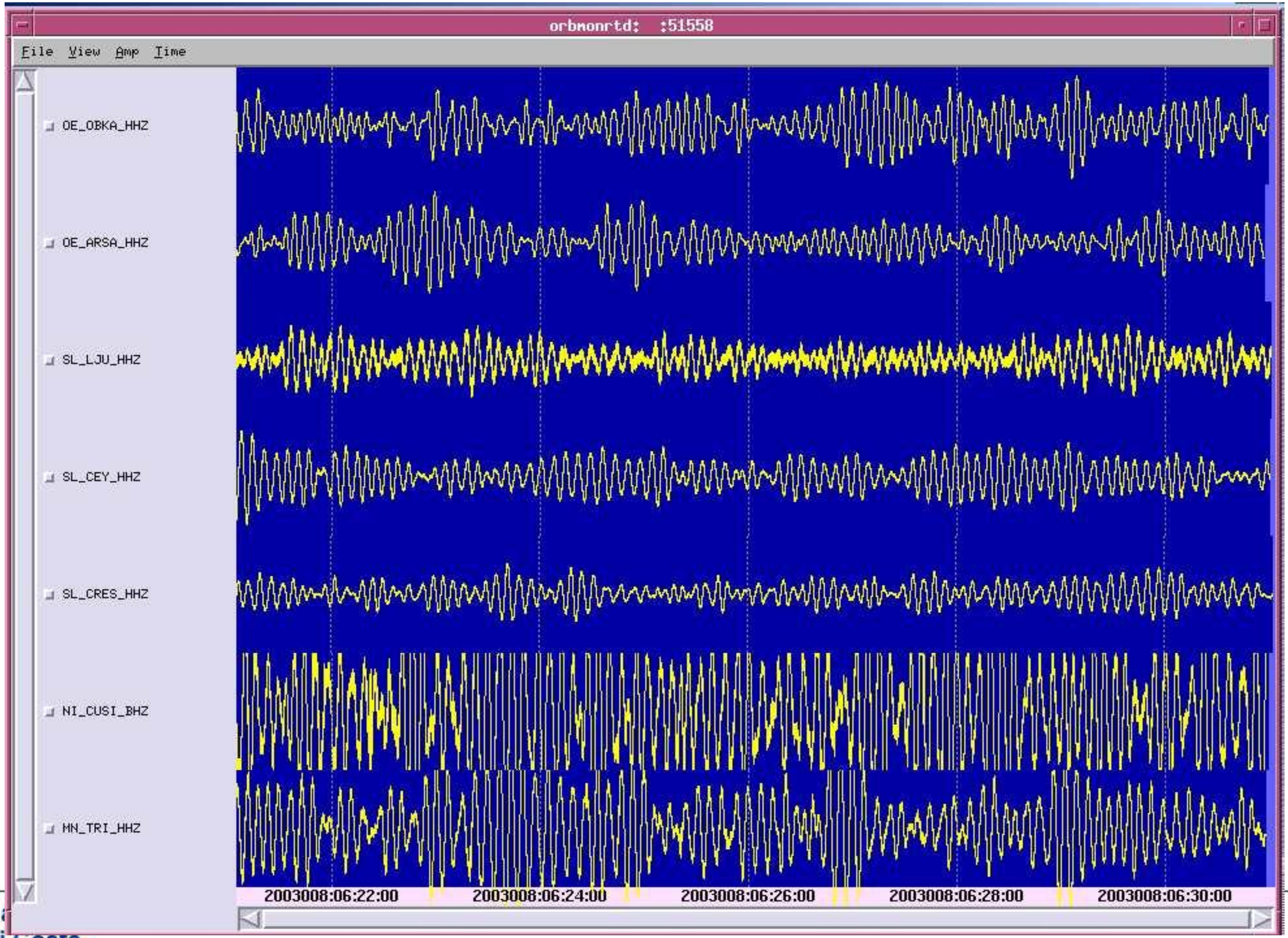
1) Site preparation has an crucial influence on results:

- temperature variation - directly and/or through induced tilts determine sensors' performance at low frequencies,

- inadequate sensor contact with bedrock can make VBB or even BB recording at low frequencies useless,

- EMI interference (shielding and grounding) can easily degrade sensors' performance at high frequencies,

- air pressure variation may degrade VBB low frequency recording.


orbmonrtd: :51558
File View Amp Time
OE_OBKA_HHZ
OE_ARSA_HHZ
SL_LJU_HHZ
SL_CEY_HHZ
SL_CRES_HHZ
NI_CUSI_BHZ
MN_TRI_HHZ
2003008:06:22:00
2003008:06:24:00
2003008:06:26:00
2003008:06:28:00
2003008:06:30:00

2) Network maintaining, that is regular sensor calibration is a crucial, frequently underestimated or even neglected issue. Fidelity of seismic records is guaranteed only between two consecutive calibration procedures of sensors, which show no significant differences between sensor transfer function. All the rest is questionable.

Re: 4 - Representativeness of data

It is solely a matter of seismic site selection and preparation.
A firm sensor contact with bedrock is required for most seismological applications where vaults must be designed for minimum soil structure interaction (light construction, ideally of the same density as surrounding soil).

What to do to assure high quality seismic data acquisition?

Proper allocation of funds among different tasks is the basis. For a new seismic system at most 50 to 70% of total funds should be spend on instrumentation. The rest should be spend on:

1) **Thorough network planning and coarse site selection. Feasibility study should consider:**

- network geometry,
- seismic noise conditions (known sources: theoretically, from the maps and by measurements, seismo-geology),

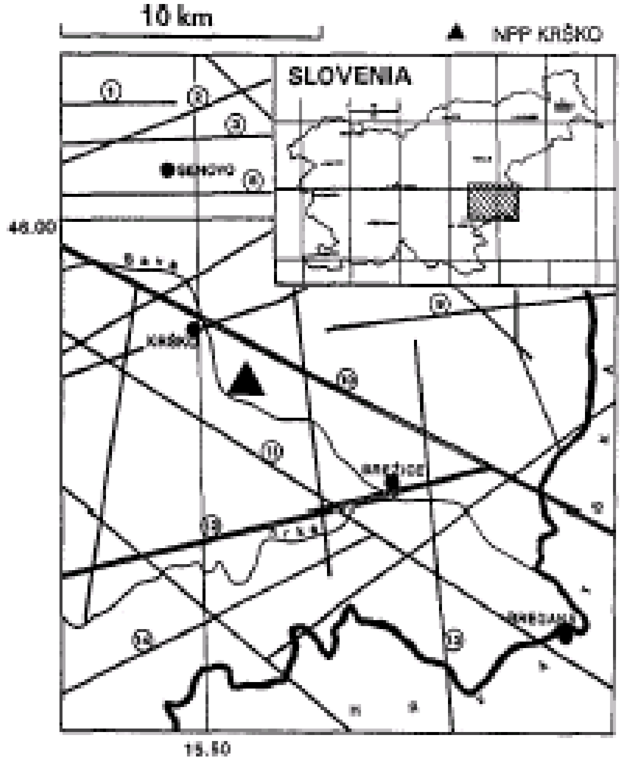


Fig. 7.1 The broader region chosen for the network in Slovenia and the main geological faults in this area (9 - Artice fault, 10 - Brestanica fault, 11 - Sava fault, 12 - Podbocje fault, 13 - Brezice fault, 14 - Orehovec fault).

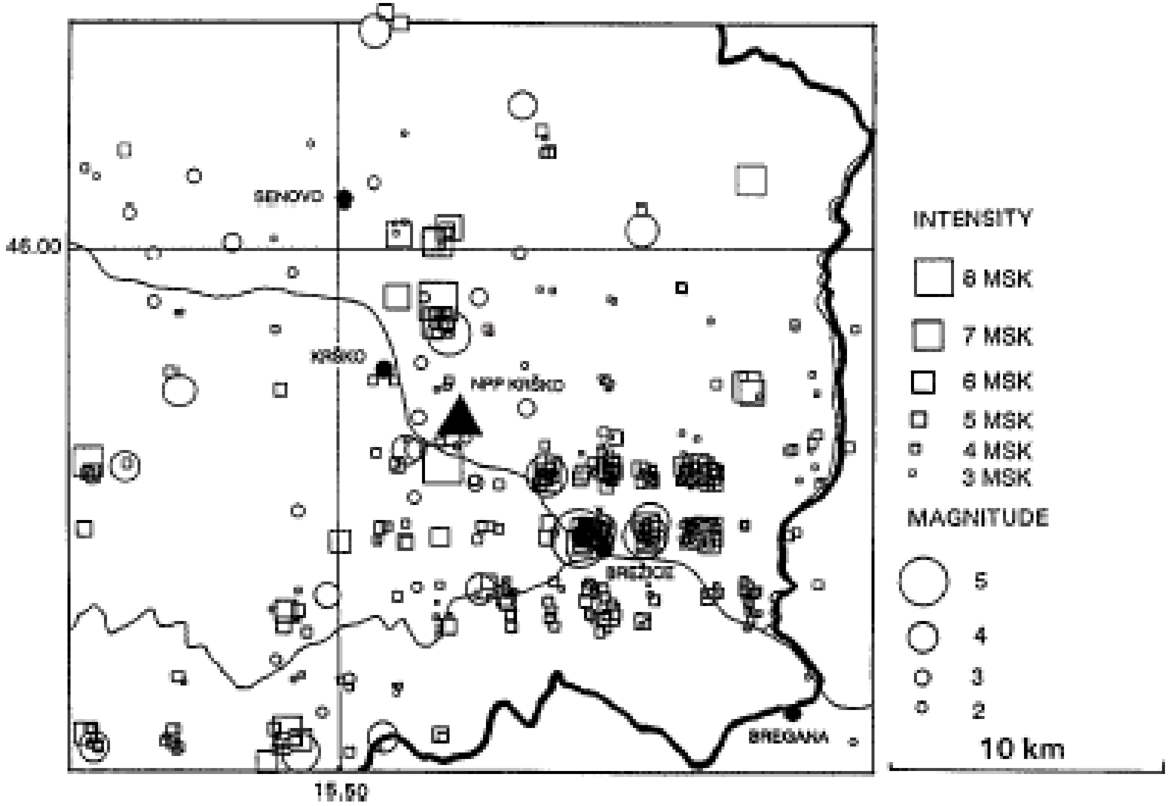


Fig. 7.2 Earthquakes in the wider region under investigation in Slovenia. The data were compiled from all available earthquake catalogs.

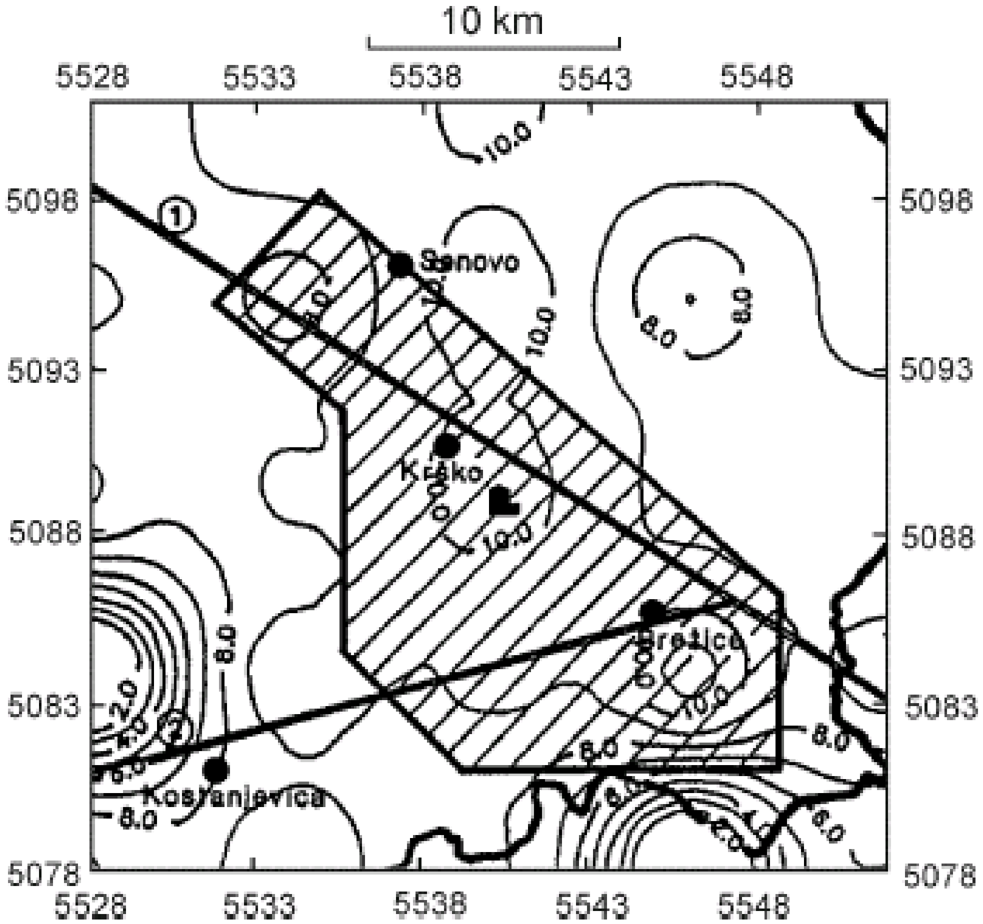


Fig. 7.3 Final choice of the area to be studied in detail by the seismic network (hatched area). Also shown are the isolines of released log-seismic energy during the time span of the catalogs (in J/km^2).

STATION SITE NAME: Loma Palo Bonito COORDINATES: N 18° 46' 58.4" W 70° 13' 20.1"		SITE #: 7 HARD ROCK, GRANITE, ETC.			DATE OF VISIT: 02/14/1998 HARDPAN HARD CLAY, ETC.			ACTUAL DISTANCE
		RECOMMENDED MINIMAL DISTANCES [km]						
		A	B	C	A	B	C	[km]
1. Oceans, coastal mountains system		300	50	1	300	50	1	75
2. Large lakes		150	25	1	150	25	1	22
3. Large dams, waterfalls	a	40	10	1	150	25	5	22
	b	60	15	5	50	15	10	
4. Large oil pipelines	a	20	10	5	30	15	5	
	b	100	30	10	100	30	10	
5. Small lakes	a	20	10	1	20	10	1	20
	b	50	15	1	50	15	1	
6. Heavy machinery, reciprocating machinery	a	15	3	1	20	5	2	25
	b	25	5	2	40	15	3	
7. Low waterfalls, rapids of a large river, intermittent flow over large dams	a	5	2	0.1	15	5	1	
	b	15	3	1	25	8	2	6
8. Railway, frequent operation	a	6	3	1	10	5	1	40
	b	15	5	1	20	10	1	
9. Airport, air traffic		6	3	1	6	3	1	
10. Non-reciprocating machinery, balanced industrial machinery	a	2	0.5	0.1	10	4	1	25
	b	4	1	0.2	15	6	1	
11. Busy highway, large farms		1	0.3	0.1	6	1	0.5	2.3
12. Country roads, high buildings		0.3	0.2	0.05	2	1	0.5	2.0
13. Low buildings, high trees and masts		0.1	0.03	0.01	0.3	0.1	0.05	0.03
14. High fences, low trees, high bushes, large rocks		0.05	0.02	5 m	0.06	0.03	0.01	0.02

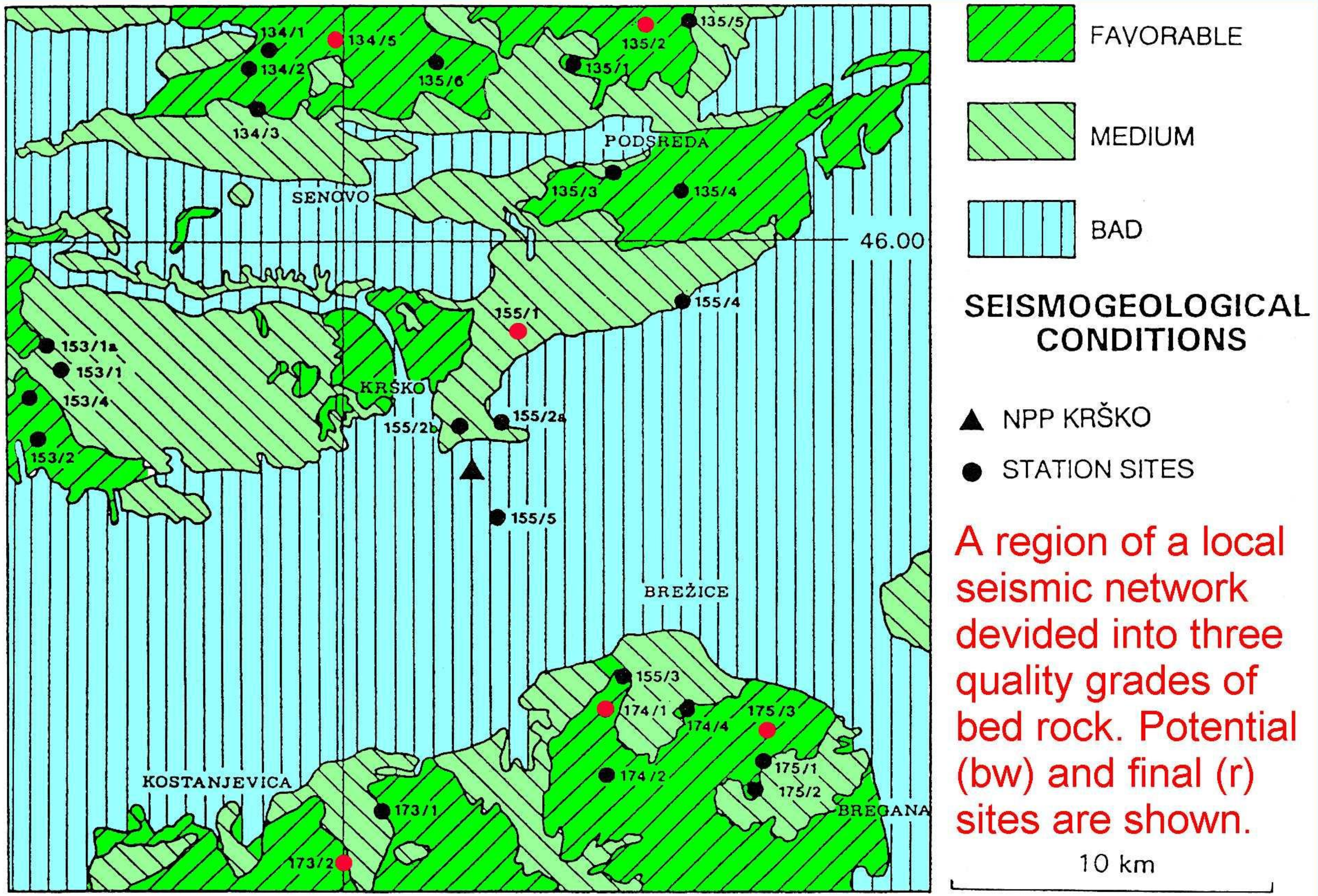
LEGEND:

- A Seismic station with a gain of 200,000 or more at 1 Hz
- B Seismic station with a gain from 50,000 to 150,000 at 1 Hz
- C Seismic station with a gain of approximately 25,000 at 1 Hz
- a Source and seismometer on widely different formations or that mountain ranges or valleys intervene
- b Source and seismometer on the same formation and with no intervening alluvial valley or mountain range

Shaded cells: The actual distance from a source of disturbance to seismometer is smaller than the recommended distance for a particular gain of seismic station, ground quality, and seismic coupling.

Fig. 7.5 Minimum recommended noise-source-to-station-site distances according to Willmore (1979) and actual distances for the seismic station Loma Palo Bonito, which is placed on hard granite rock.

Transparency 4



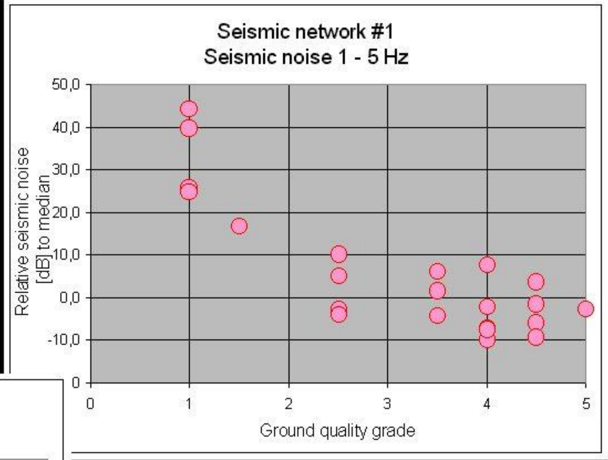
A region of a local seismic network devided into three quality grades of bed rock. Potential (bw) and final (r) sites are shown.

GROUND QUALITY

1) unconsolidated clastic sediments (clays, gravels sands, fluvial sediments, muds, lacustrine sediments, river and glacial sediments, marine sediments)

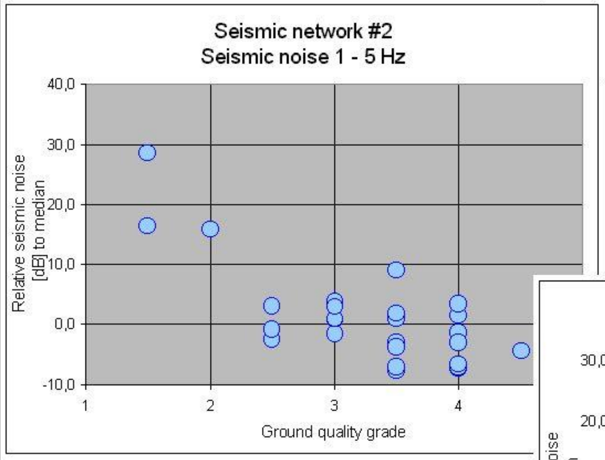
2) clastic sediments (claystones, marls, marlstones, flysch, sandstones, tuffs, marly limestones, ither schists)

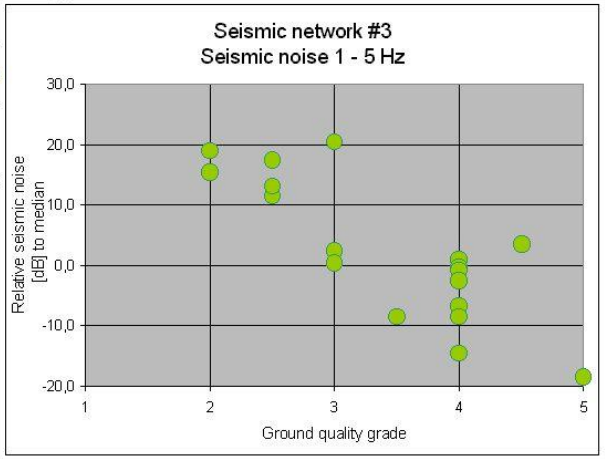
3) well cemented clastic sediments and carbonate rocks (limestones, dolomites, sandstones, conglomerates, breccias, cherts)



4) carbonate solid rocks (limestones, dolomites), compact metamorphic rocks (gneisses, micaschists, marbles), and bed magmatic rocks

5) magmatic rocks (granites, granodiorites, basalts, diabases, tonalites)

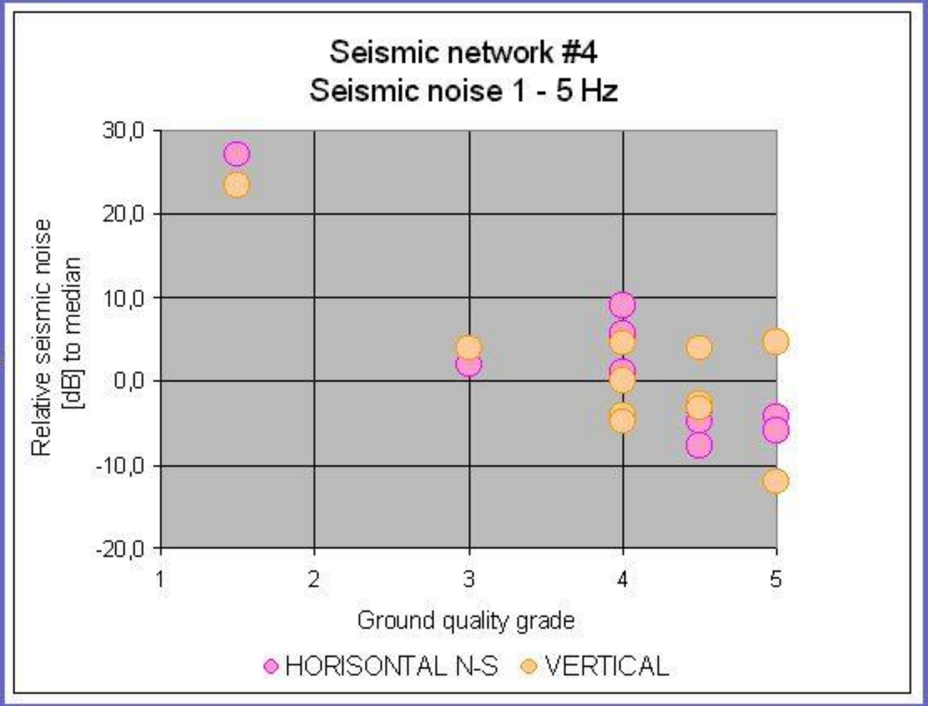




Transparency 5

Transparency 6

Correlation between seismic noise and ground quality estimate. A clear correlation exists. Differences in noise are very large. However, sites at high quality bedrock still have a large scatter in seismic noise. Noise measurements are thus needed.



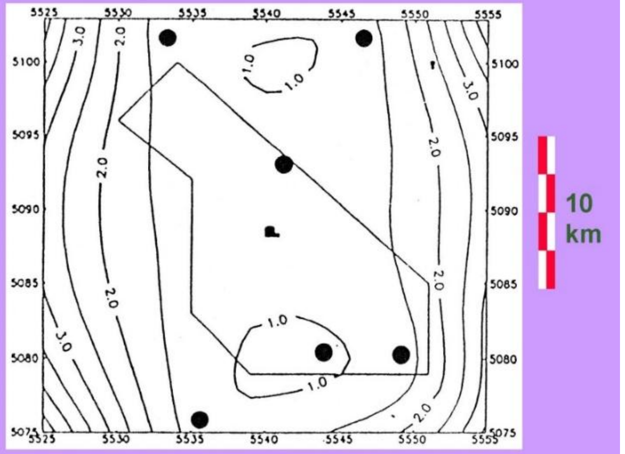
What to do to assure high quality seismic data acquisition?

Proper allocation of funds among different tasks is the basis. For a new seismic system at most 50 to 70% of total funds should be spend on instrumentation. The rest should be spend on:

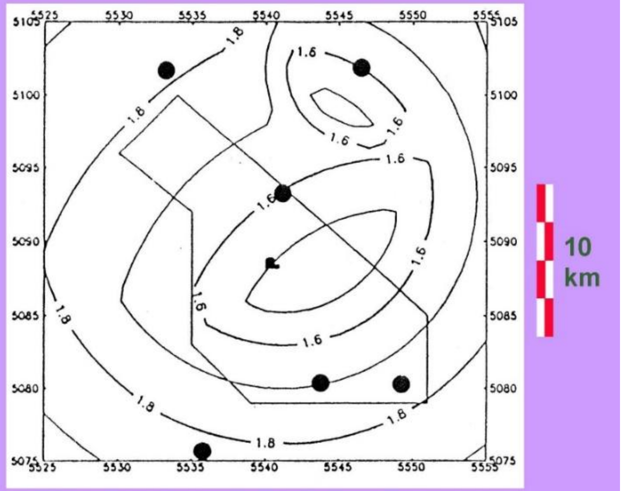
1) **Thorough network planning and coarse site selection. Feasibility study should consider:**

- network geometry,
- seismic noise conditions (known sources: theoretically, from the maps and by measurements, seismo-geology),
- exploitational conditions (access, power lines availability, communication infrastructure),
- topographical and climates conditions (wind, precipitation),
- modeling of performances of a few most probable geometry of networks.

Transparency 7



Isolines of the uncertainty of epicenter determination for events recorded at all six stations of the network. Standard deviation in km is shown.



Isolines of the minimal magnitude of events that are recorded at least on 5 stations with seismic signal/noise ratio at least 20 dB.

Fig. 7.6 Map of the seismic network region with all potential station sites (full dots) and known seismic noise sources (roads, railway, cities, villages, industrial facilities, quarries, etc) with circles of minimum recommended distances drawn around them for the case of gain 25.000 for a SP seismic stations at 1 Hz set on hard clay, hardpan and similar ground, i.e., case C, d (i.e., source and seismometer on same formation and with no intervening alluvial valley or mountain range) according to Willmore (1979).

What to do to assure high quality seismic data acquisition?

Proper allocation of funds among different tasks is the basis. For a new seismic system at most 50 to 70% of total funds should be spend on instrumentation. The rest should be spend on:

2) Educated site selection procedure (micro locations)

- seismic noise measurements,
- search for local intermittent man-made seismic noise sources,

What to do to assure high quality seismic data acquisition?

Proper allocation of funds among different tasks is the basis. For a new seismic system at most 50 to 70% of total funds should be spend on instrumentation. The rest should be spend on:

2) Educated site selection procedure (micro locations)

- seismic noise measurements,
- search for local intermittent man-made seismic noise sources,
- verification of local geology conditions and access,
- verification of availability of power lines and communication lines,
- verification of local RF conditions (if applicable).

What to do to assure high quality seismic data acquisition?

Proper allocation of funds among different tasks is the basis. For a new seismic system at most 50 to 70% of total funds should be spend on instrumentation. The rest should be spend on:

3) Proper site preparation

- assure contact with bedrock,
- search for local intermittent man-made seismic noise sources,
- maintain appropriate conditions to exploit all benefits of modern sensors (sufficient thermal insulation),
- apply lightning protection measures based on actual lightning treat at individual sites and build grounding system,

Lightning protection is an indispensable infrastructure precondition for a failure free operation of complex seismic equipment.

Protection system design involves:
- Surge protection devices (SPD) for power lines,
- Surge protection devices for phone and/or Ethernet lines,
- Surge protection of local signal lines (analogue seismic, data, GPS, UHF/VHF/SS RF cables),
- Electric Ground and Grounding System,
- Shielding,
- Proper cabling.

Power line protection includes SPD Class A, B, (7m) C, and D protection at ~230V wall outlets, plus equipment internal protection. It assures:
- protection against lightning currents
- protection against common mode overvoltage
- protection against differential overvoltage

Issues involved:
- probability of lightning,
- type of distribution system (source grounding, neutral and protection conductor arrangement),
- position of power meter,
- type of load (fixed/portable)
- local soil resistivity.

Rule #1

Lightning treat may vary in a ratio of 1 : >1.000 among different sites (topography, climate, geographical latitude). Thus applying the same protection measures on all sites means wasting money. Not applying them is usually an even worse wasting of money.

Rule #2

Apply measures on all cables or on non! Lightning treat paths are logically OR wired! Use professionals' help.

What is lightning treat?

Atmospheric discharge currents 10 kA to 200 kA, induced voltages > 1.000 times exceed instrumentation insulation voltage.

Type of damages:

- mechanical damages,
- thermal damages,
- insulation breakage of electronic parts and cables.

Damages can be caused by:

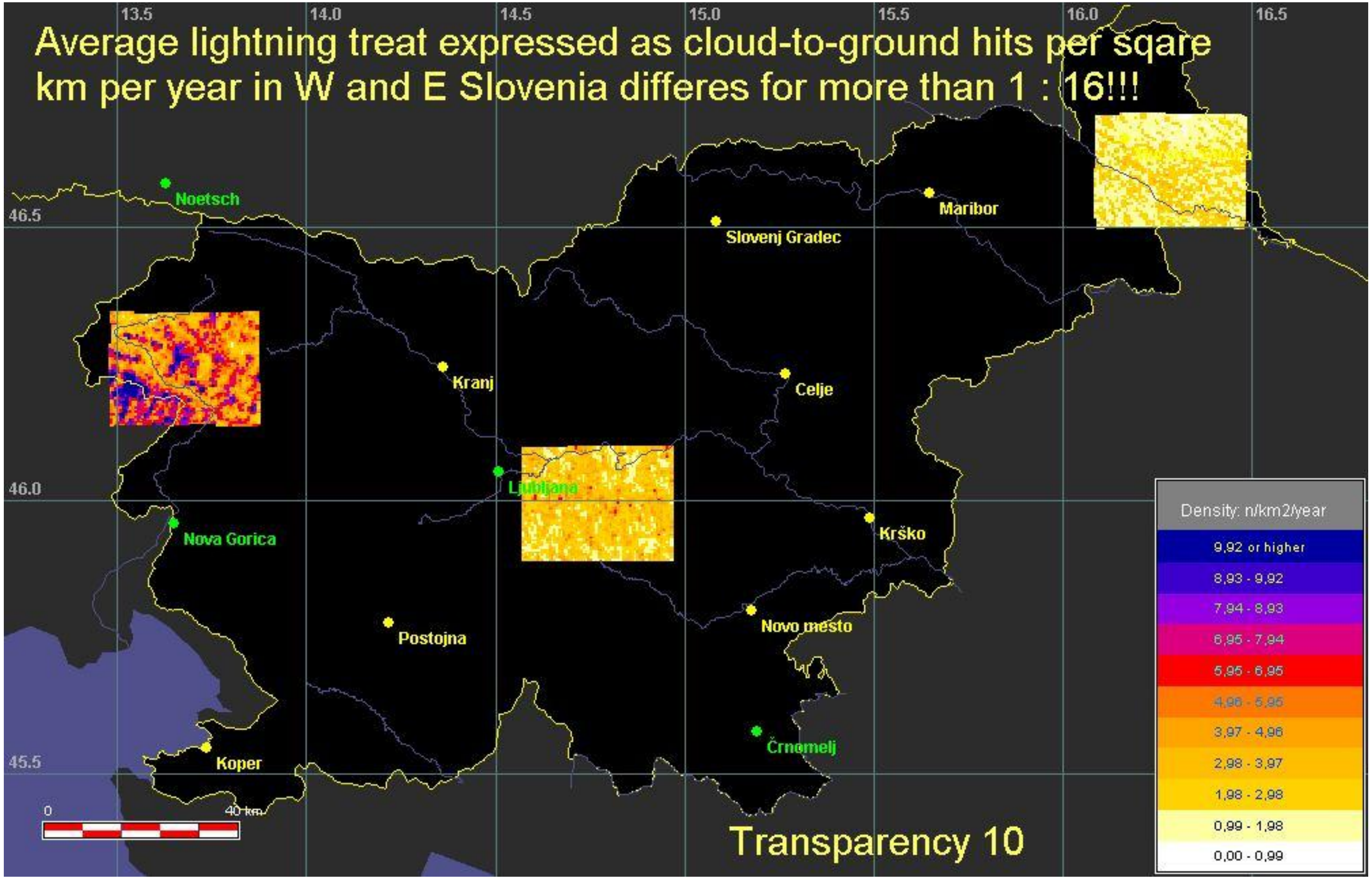
a- direct hit cloud-ground of the main discharge path (equipment must be very extensively protected to withstand, too expensive for seismology),

b- direct side branch hit cloud–ground (hard to protect but feasible),

c- indirect induction caused by cloud–cloud discharge is most frequent (accumulated charge redistribution currents, voltage induction through magnetic fields). In average 1.5 km zone of danger (stand alone facility) and 5 km with interconnected facilities (power, lines, phone lines, water pipes).

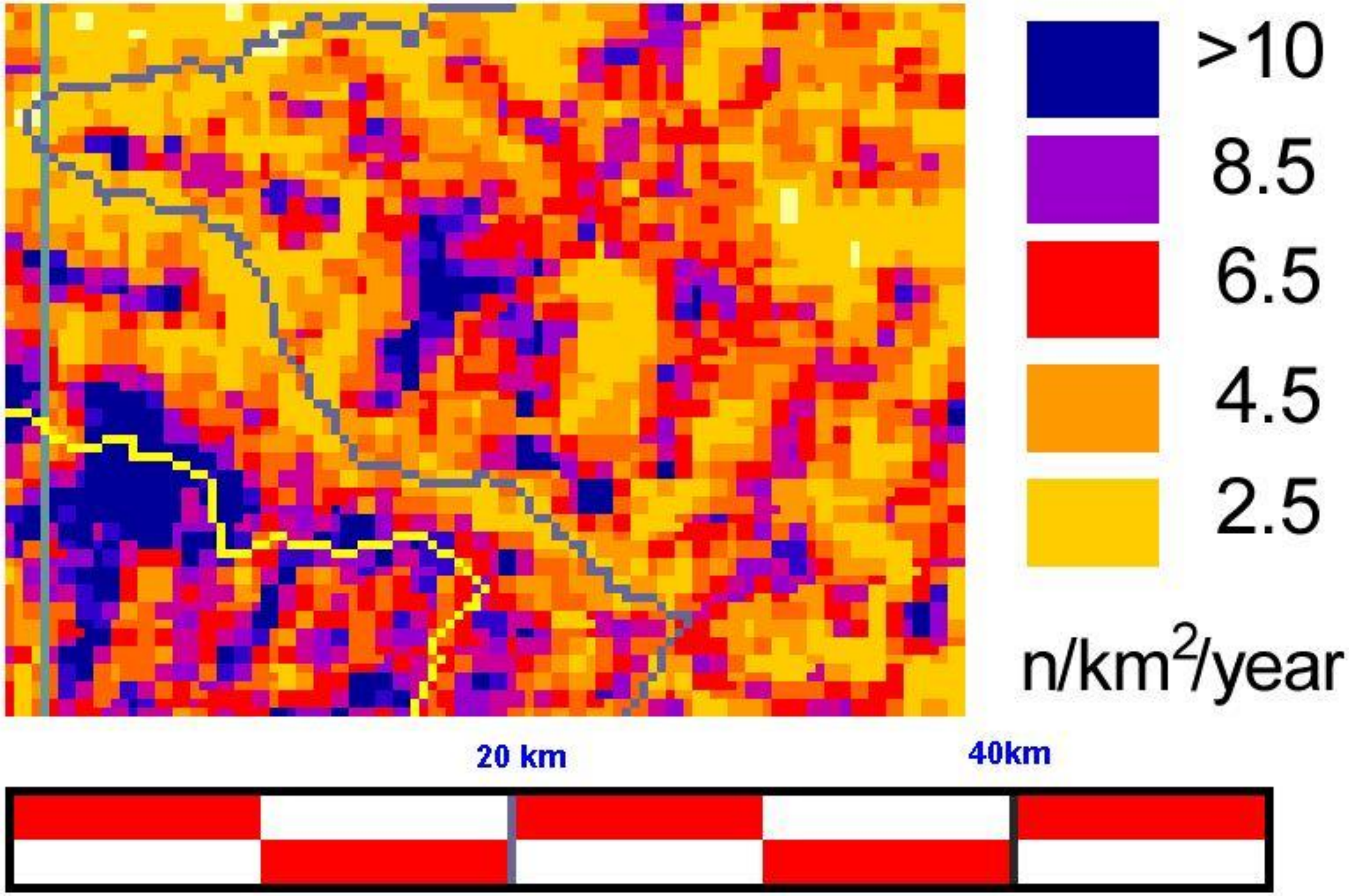
Different protection elements in use:

- resistors
- inductors
- gas discharge devices
- PTC resistors
- thermal fuses
- varistors
- mono- and bi-directional suppressor diodes

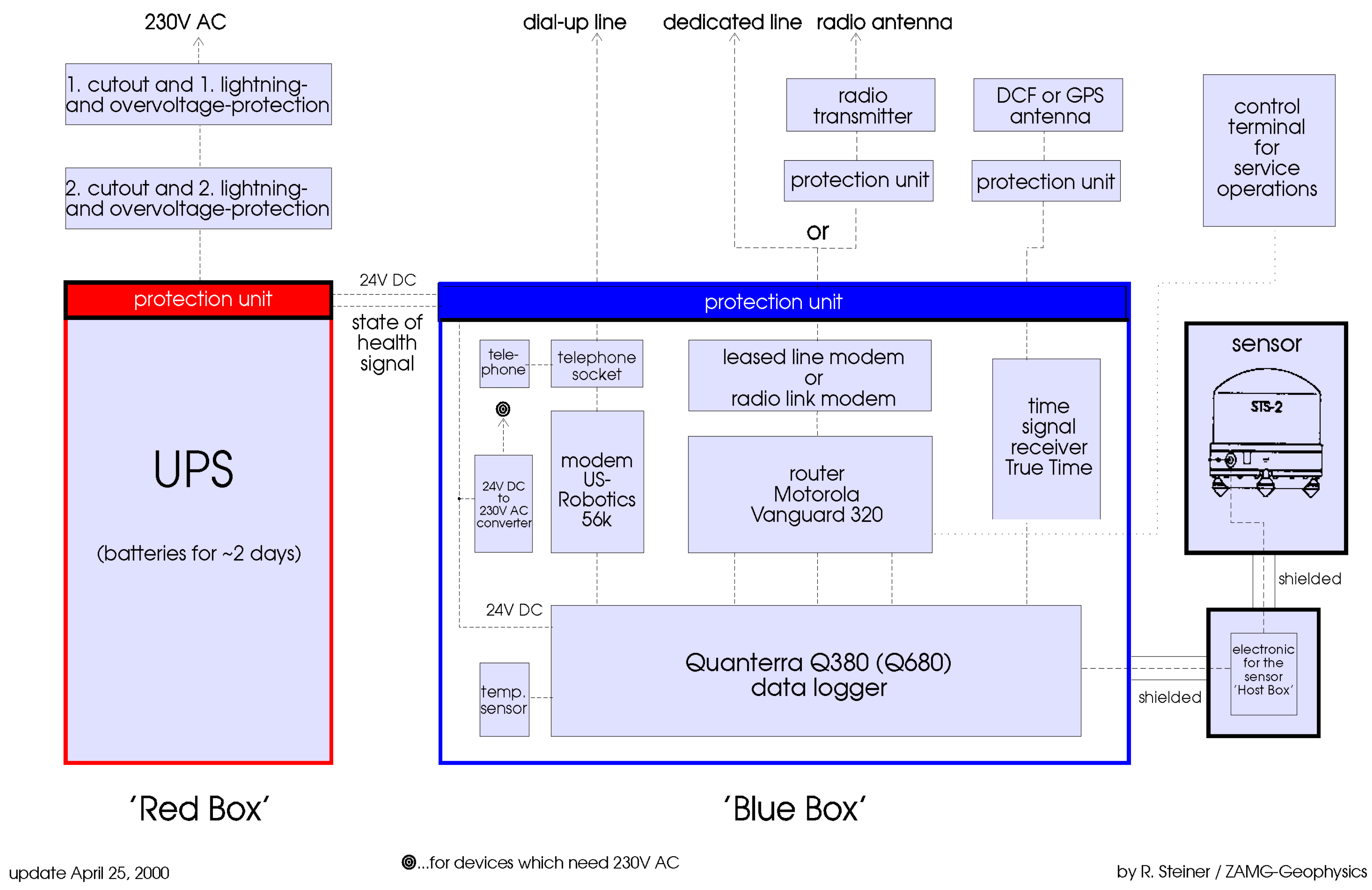


Average lightning treat expressed as cloud-to-ground hits per sqare km per year in W and E Slovenia differes for more than 1 : 16!!!
13.5
14.0
14.5
15.0
15.5
16.0
16.5
46.5
46.0
45.5
Noetsch
Slovenj Gradec
Maribor
Kranj
Celje
Ljubljana
Nova Gorica
Krško
Postojna
Novo mesto
Črnomelj
Koper
0
40 km
Transparency 10
Density: n/km2/year
9,92 or higher
8,93 - 9,92
7,94 - 8,93
6,95 - 7,94
5,95 - 6,95
4,96 - 5,95
3,97 - 4,96
2,98 - 3,97
1,98 - 2,98
0,99 - 1,98
0,00 - 0,99

Transparency 11

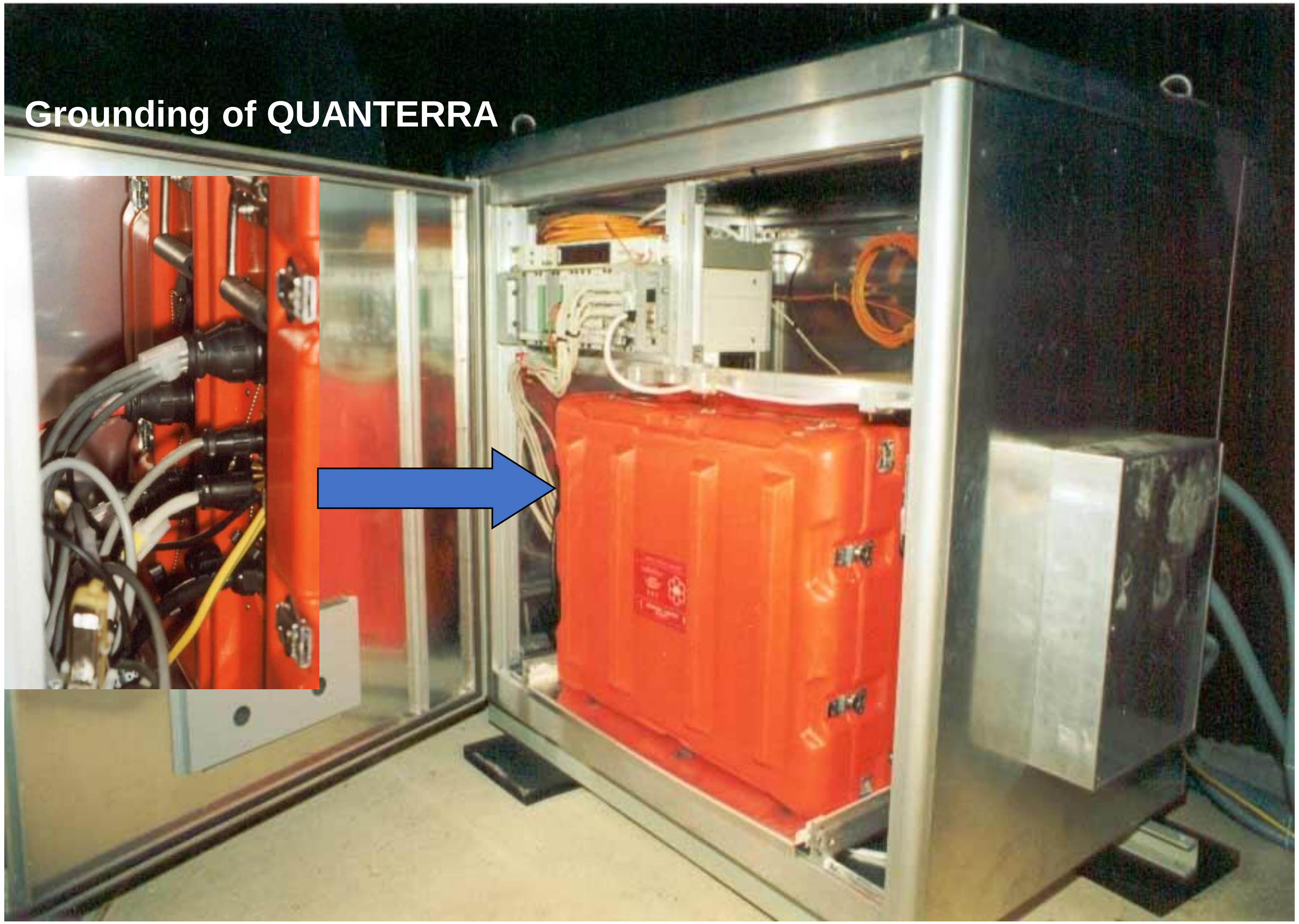


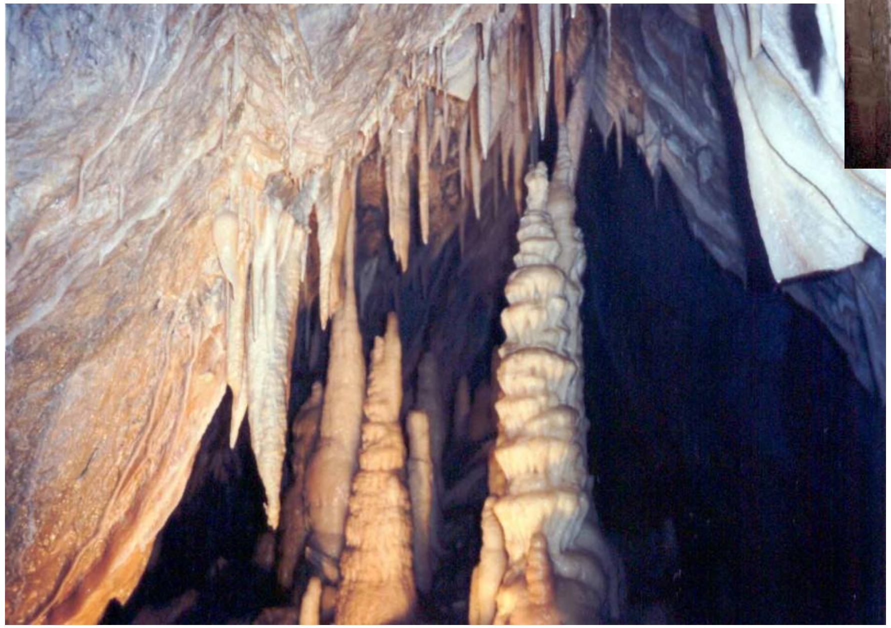
Even on local scale (a few km distance) lightning treat may differ for more than 1:4. North-west Slovenia, a mountain region.

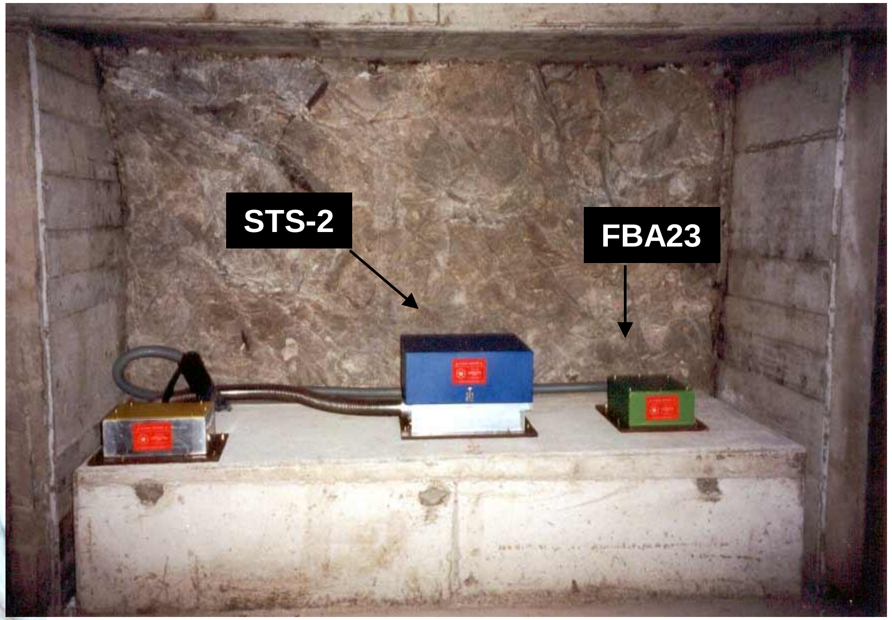

230V AC
1. cutout and 1. lightning- and overvoltage-protection
2. cutout and 2. lightning- and overvoltage-protection
protection unit
UPS
(batteries for ~2 days)
'Red Box'
24V DC
state of health signal
dial-up line
dedicated line
radio antenna
radio transmitter
protection unit
or
DCF or GPS antenna
protection unit
control terminal for service operations
protection unit
tele-phone
telephone socket
leased line modem or radio link modem
24V DC to 230V AC converter
modem US-Robotics 56k
router Motorola Vanguard 320
time signal receiver True Time
24V DC
temp. sensor
Quanterra Q380 (Q680) data logger
sensor
STS-2
shielded
electronic for the sensor 'Host Box'
shielded
'Blue Box'
update April 25, 2000
...for devices which need 230V AC
by R. Steiner / ZAMG-Geophysics

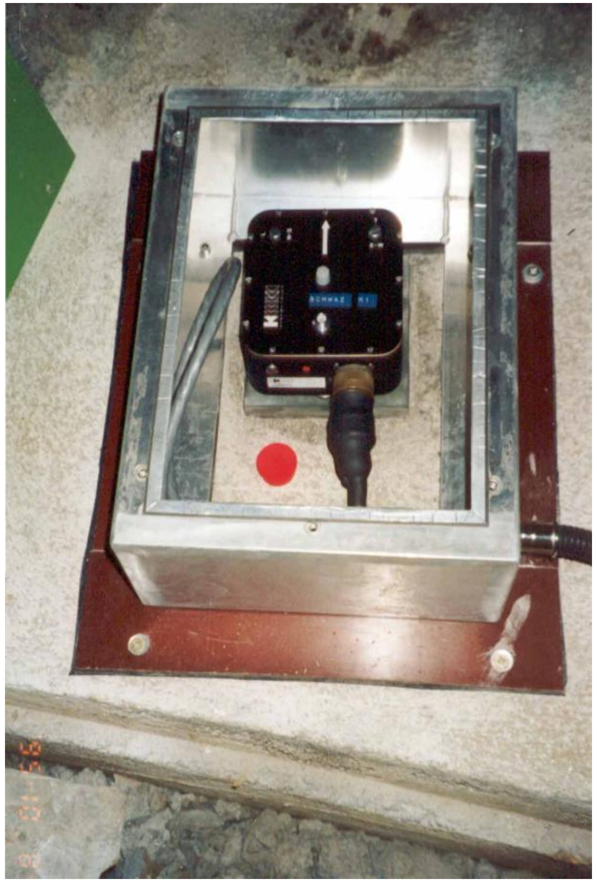

Cover against air flow,and water drops
and temperature changes
Surge protected cable
Metal grid for magnetic
shielding
Isolation against humidity

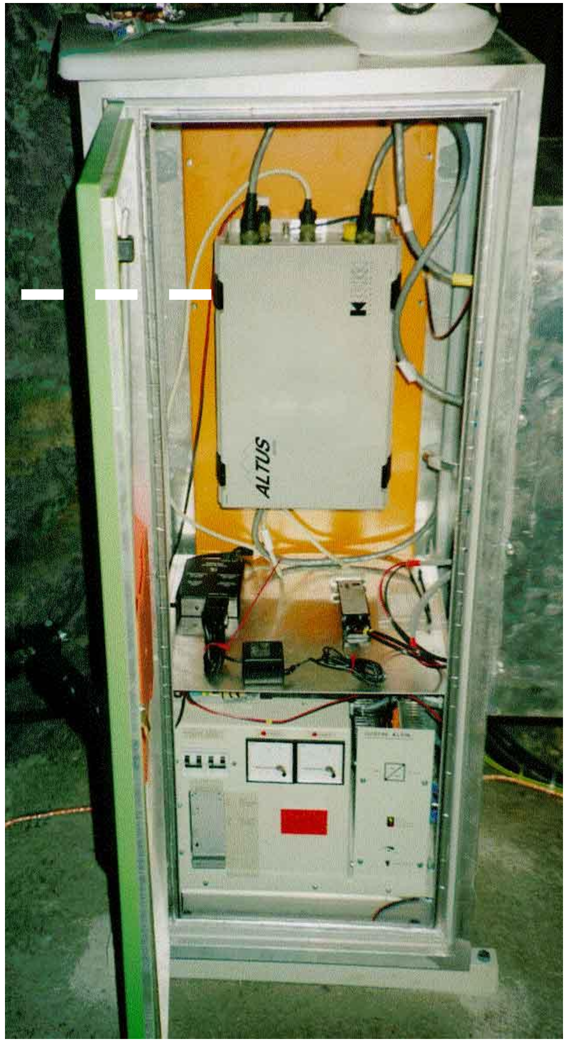
Grounding of QUANTERRA

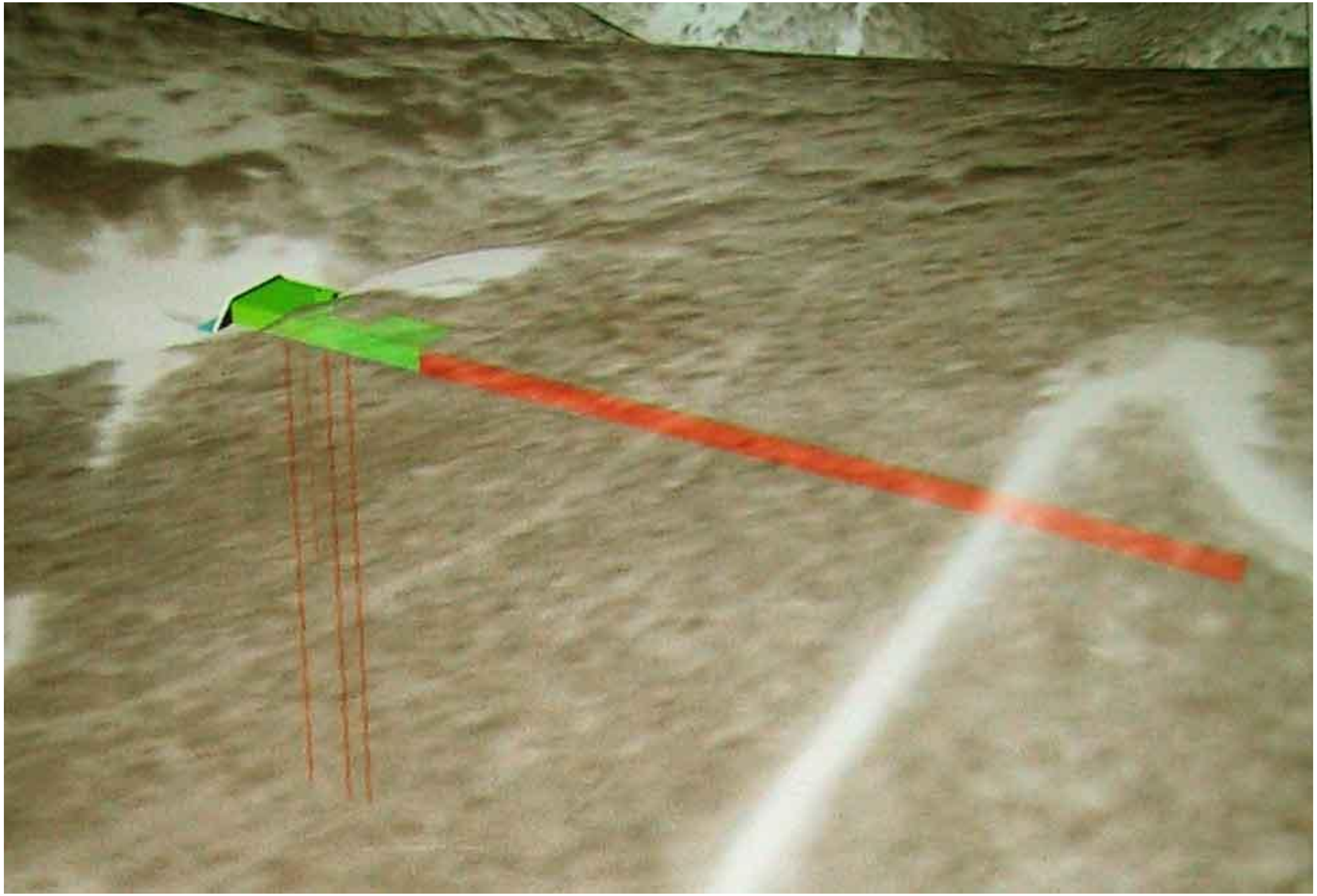




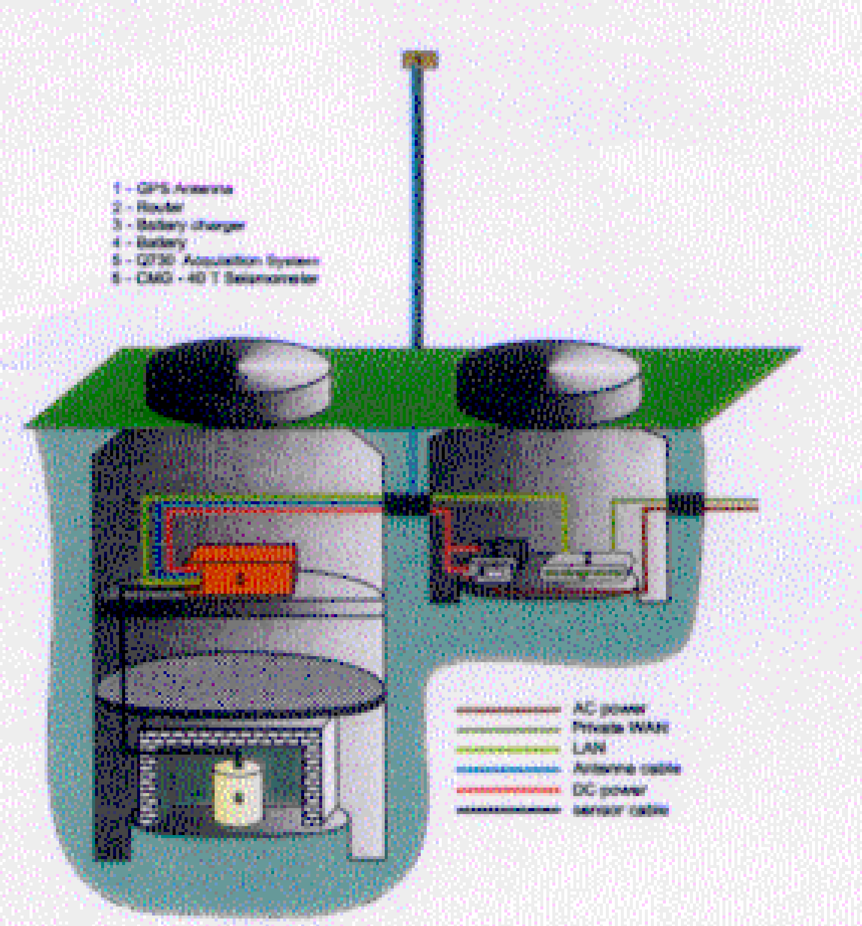

STS-2
FBA23

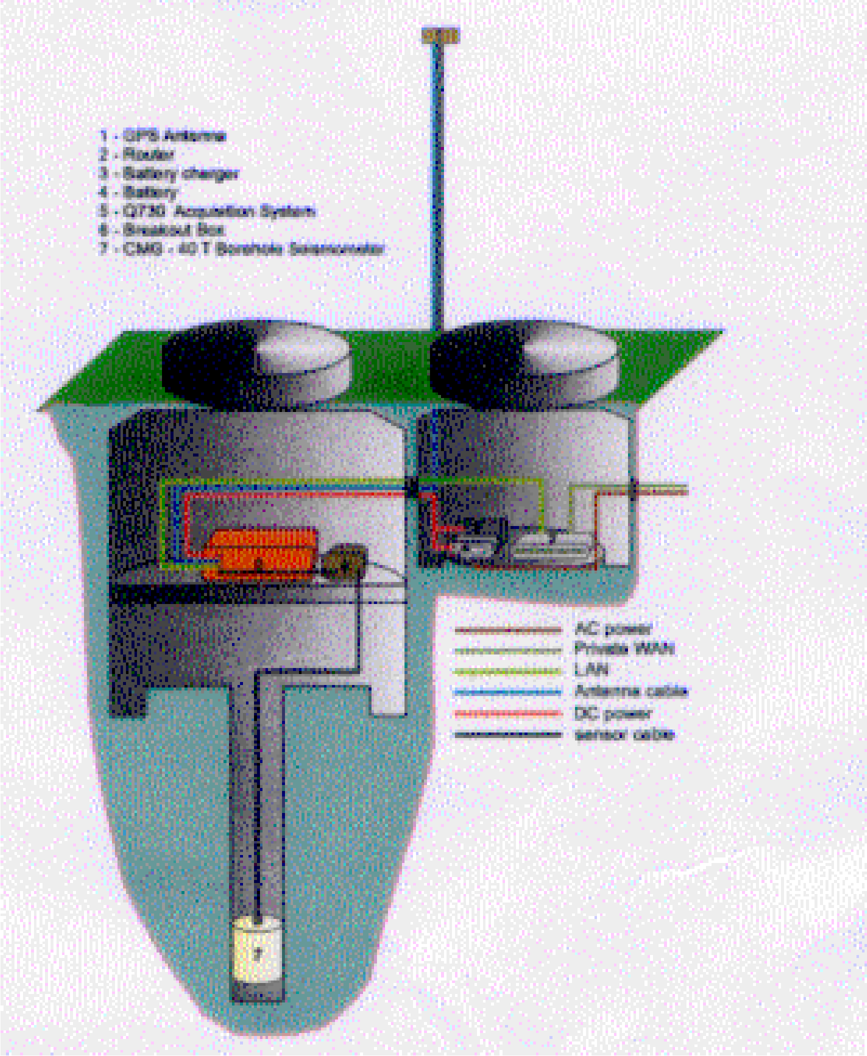


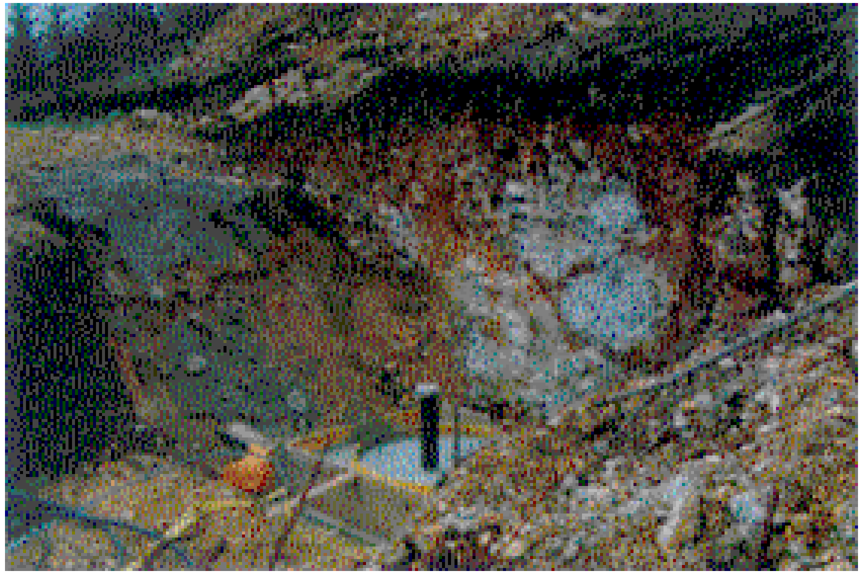

ALTUS

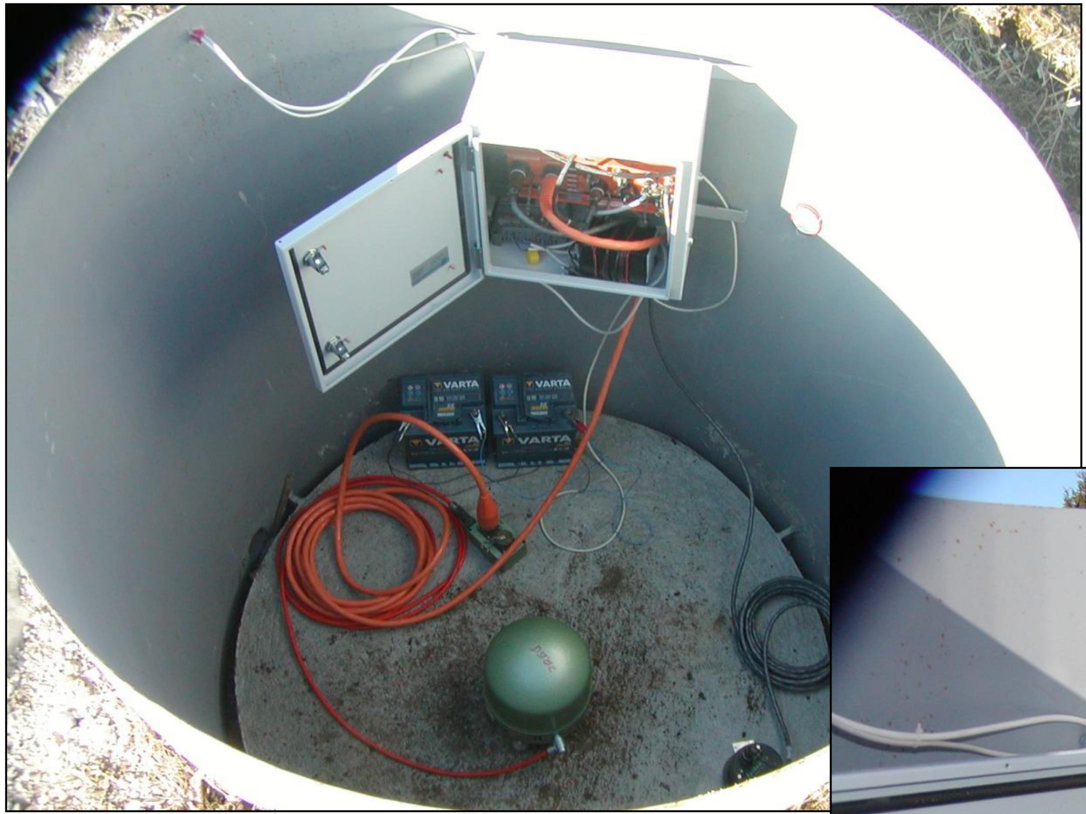



NW-SCHRANK 5
REMOTE CONTROL SYSTEM
NW-SCHRANK 4
CAT.6-SAMMELVERTEILER


1 - GPS Antenna
2 - Router
3 - Battery charger
4 - Battery
5 - Q730 Acquisition System
6 - CMG - 40 T Seismometer
AC power
Private WAN
LAN
Antenna cable
DC power
sensor cable

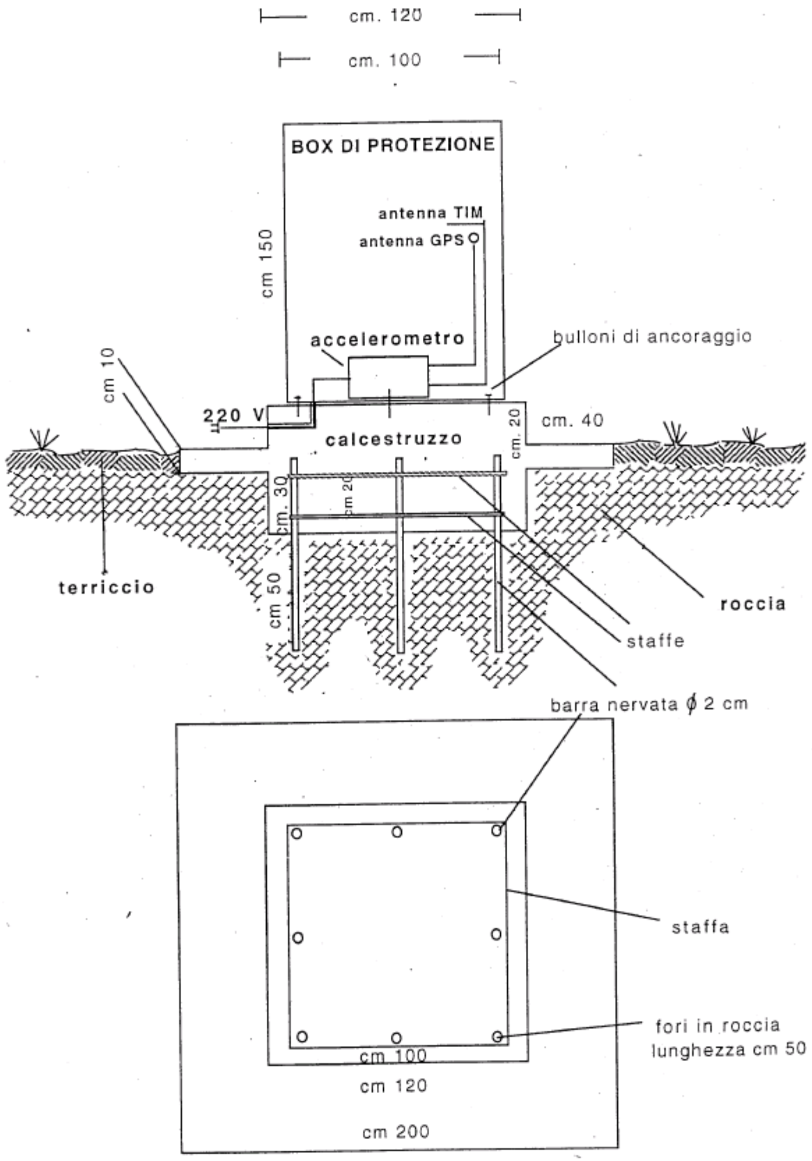

1 - GPS Antenna
2 - Router
3 - Battery charger
4 - Battery
5 - Q730 Acquisition System
6 - Breakout Box
7 - CMG - 40 T Borehole Seismometer
AC power
Private WAN
LAN
Antenna cable
DC power
sensor cable




VARTA


QUANTERRA Q330


GEMONA
VIA ROMA


cm. 120
cm. 100
BOX DI PROTEZIONE
antenna TIM
antenna GPS
cm 150
accelerometro
bulloni di ancoraggio
cm 10
220 V
calcestruzzo
cm. 20
cm. 40
cm. 30
cm 50
terriccio
roccia
staffe
barra nervata ϕ 2 cm
staffa
fori in roccia
lunghezza cm 50
cm 100
cm 120
cm 200

Il Palazzo Carciotti e la nuova stazione accelerometrica CARC della RAF.

What to do to assure high quality seismic data acquisition?

Proper allocation of funds among different tasks is the basis. For a new seismic system at most 50 to 70% of total funds should be spend on instrumentation. The rest should be spend on:

3) Proper site preparation

- assure contact with bedrock,
- search for local intermittent man-made seismic noise sources,
- maintain appropriate conditions to exploit all benefits of modern sensors (sufficient thermal insulation),
- apply lightning protection measures based on actual lightning treat at individual sites and build grounding system,
- assure vault water tightness,
- assure minimum soil-structure interaction (light design of the vaults),
- mitigate local seismic noise sources (wind and shelters, antenna mast, fencing, power transformers, electromechanical devices within the vault, insufficiently tight vault cover).

What to do to assure high quality seismic data acquisition?

Proper allocation of funds among different tasks is the basis. For a new seismic system at most 50 to 70% of total funds should be spend on instrumentation. The rest should be spend on:

4) Regular maintaining

- regular verification (charge capacity measurements, not voltage measurements!) and in-time replacement of batteries,
- periodic remote control of state of health of stations (if available),
- periodic on site visits and verification of potential damages (advancing corrosion, small cable, solar panel, antennae damages, light water intrusion or of small animals, vandalism attempts, cleaning vaults)
- periodic sensor calibration, thorough documentation of results, and archiving.

MAGNETOTERMICI

SALVAVITA riarmo automatico

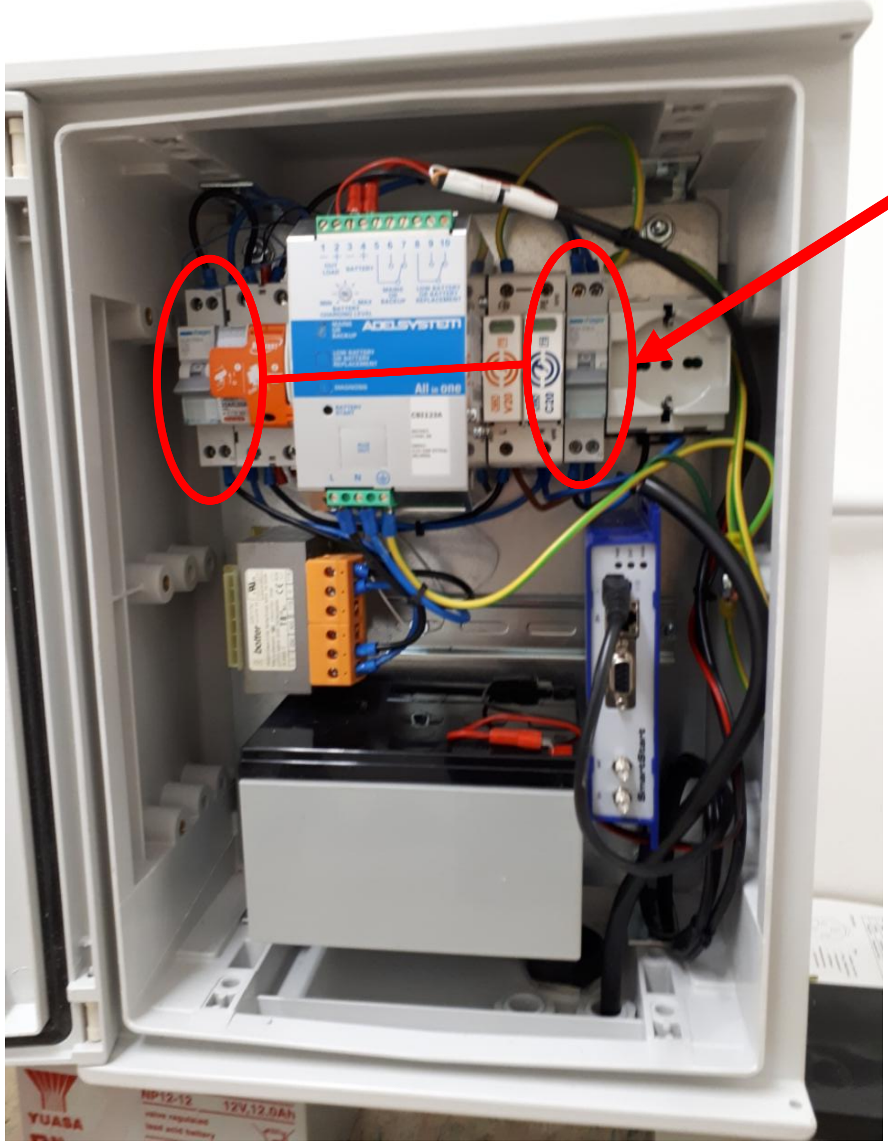
SCARICATORI

TRASFORMATORE DISCONTINUITA’

UPS

BATTERIA

ROUTER



MAGNETOTERMICI

SALVAVITA riarmo automatico

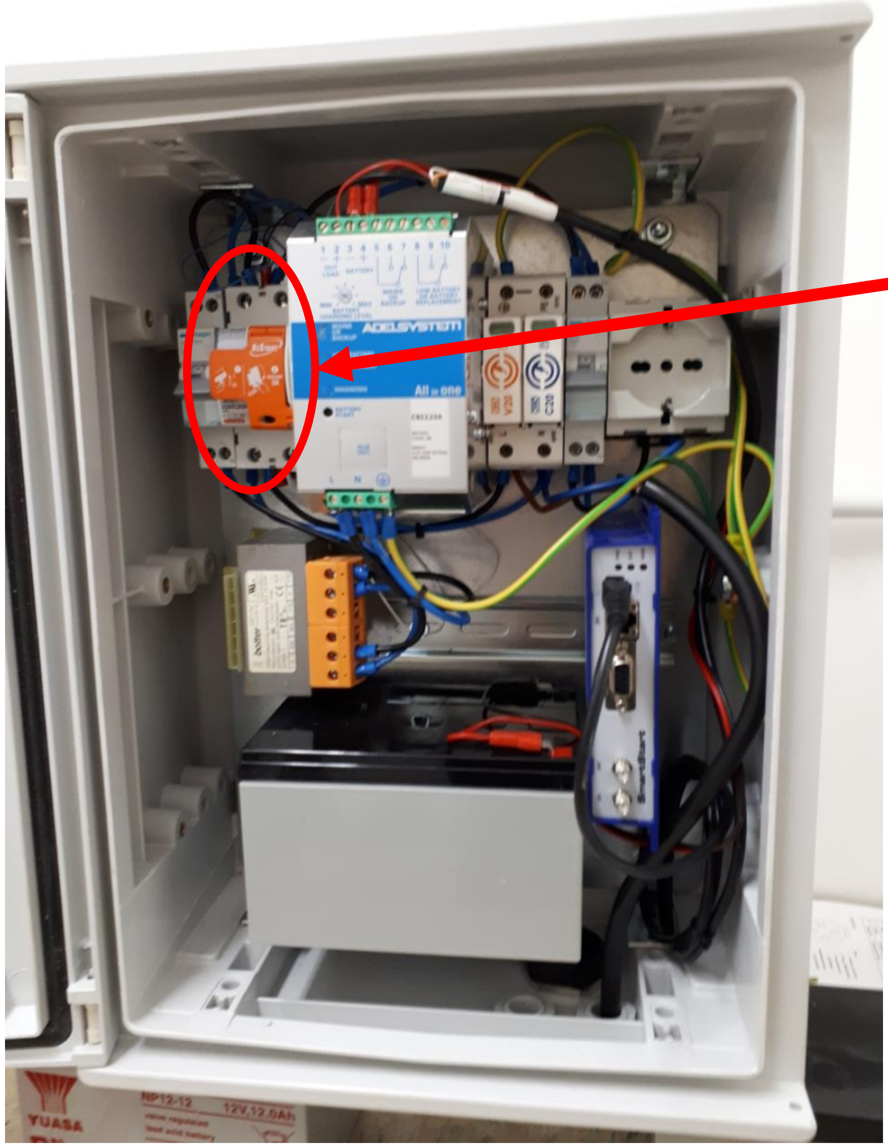
SCARICATORI

TRASFORMATORE DISCONTINUITA’

UPS

BATTERIA

ROUTER



MAGNETOTERMICI

SALVAVITA riarmo automatico

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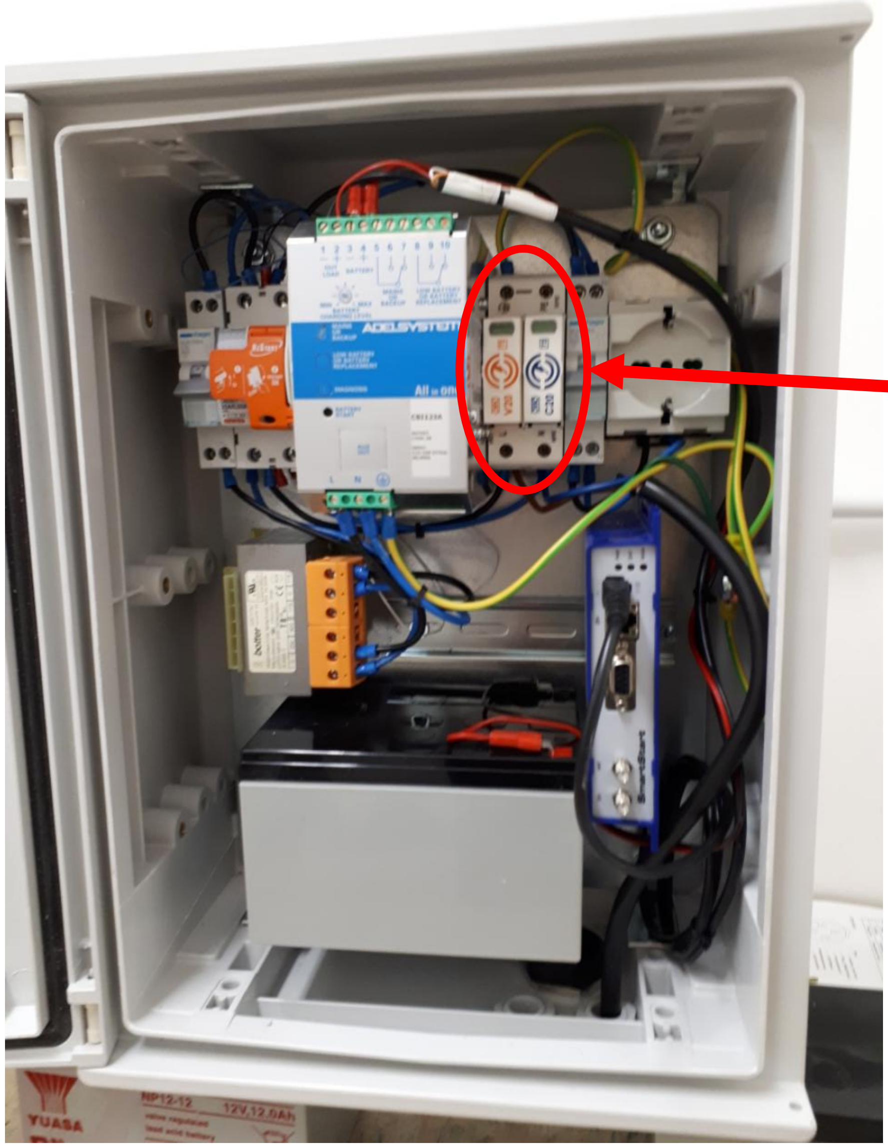

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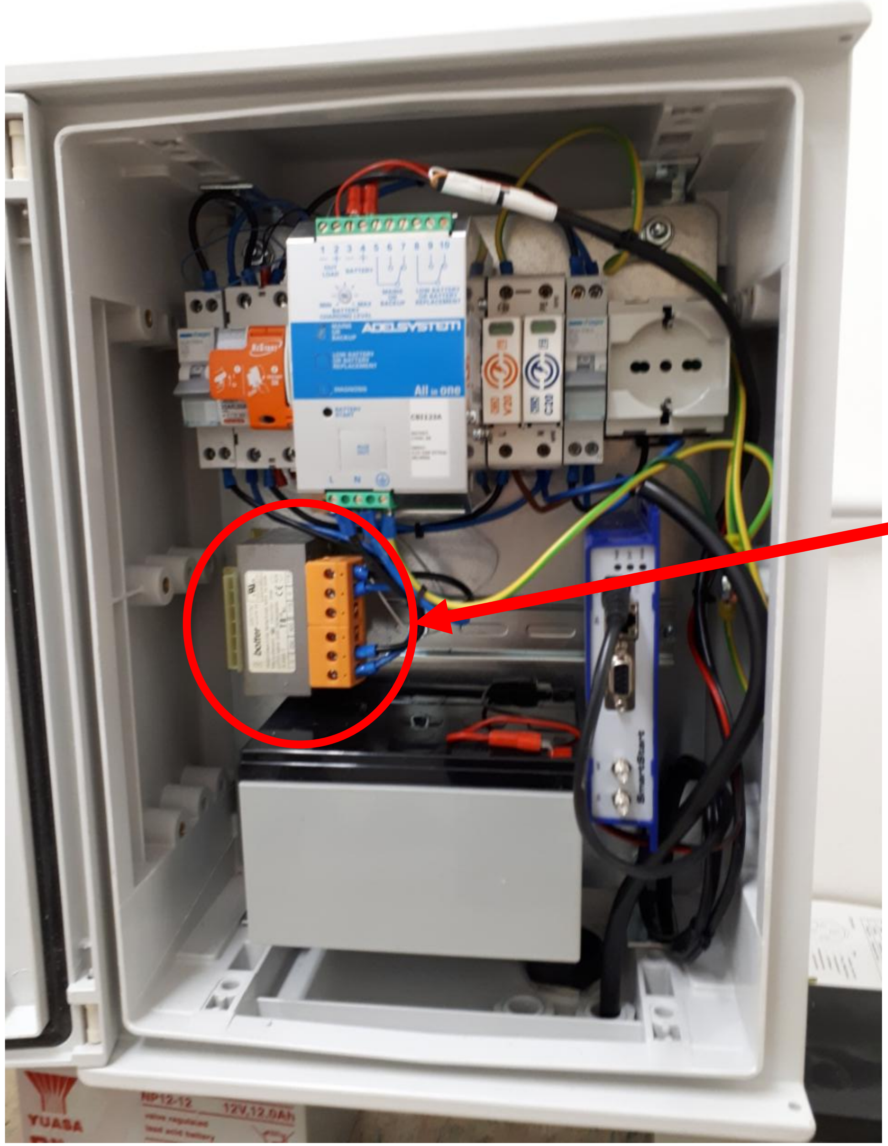

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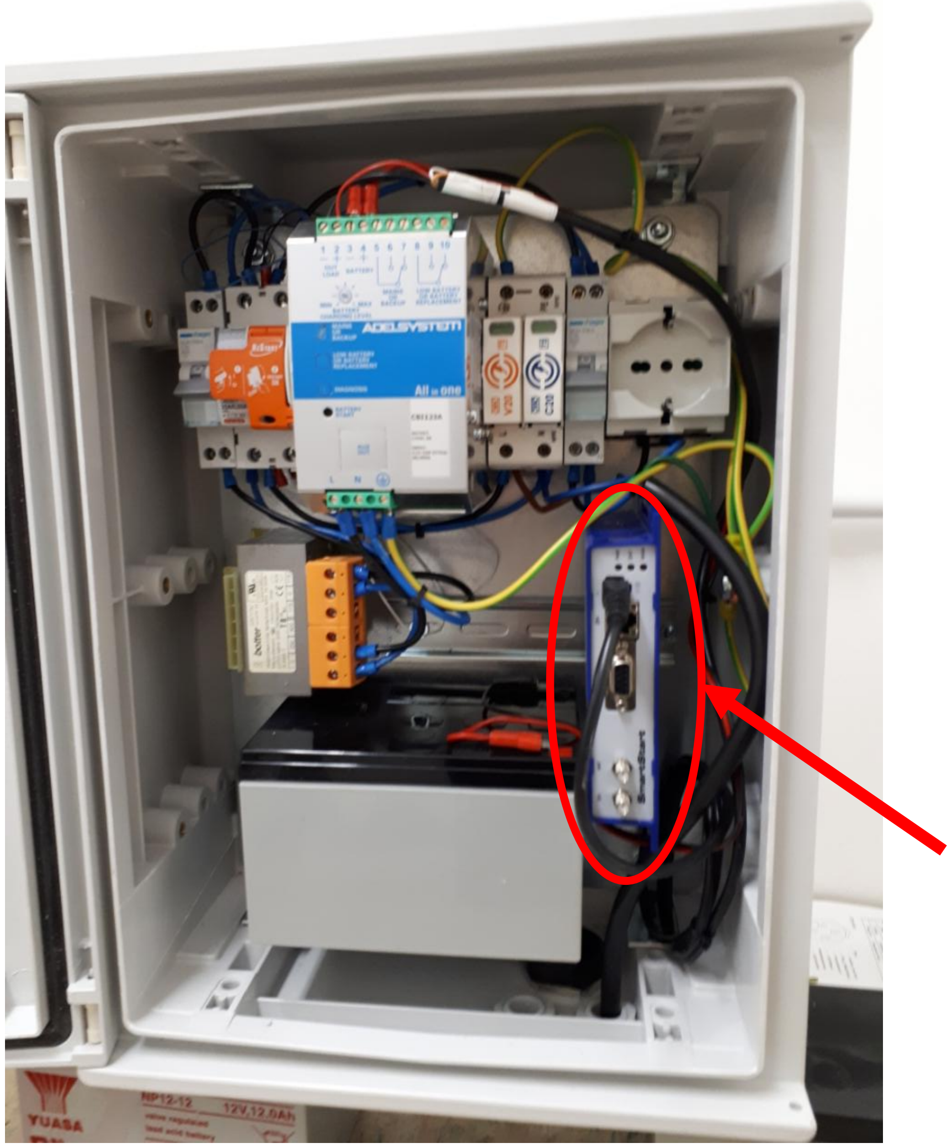

MAGNETOTERMICI

SALVAVITA riarmo automatico

SCARICATORI

TRASFORMATORE DISCONTINUITA'

UPS

BATTERIA

ROUTER