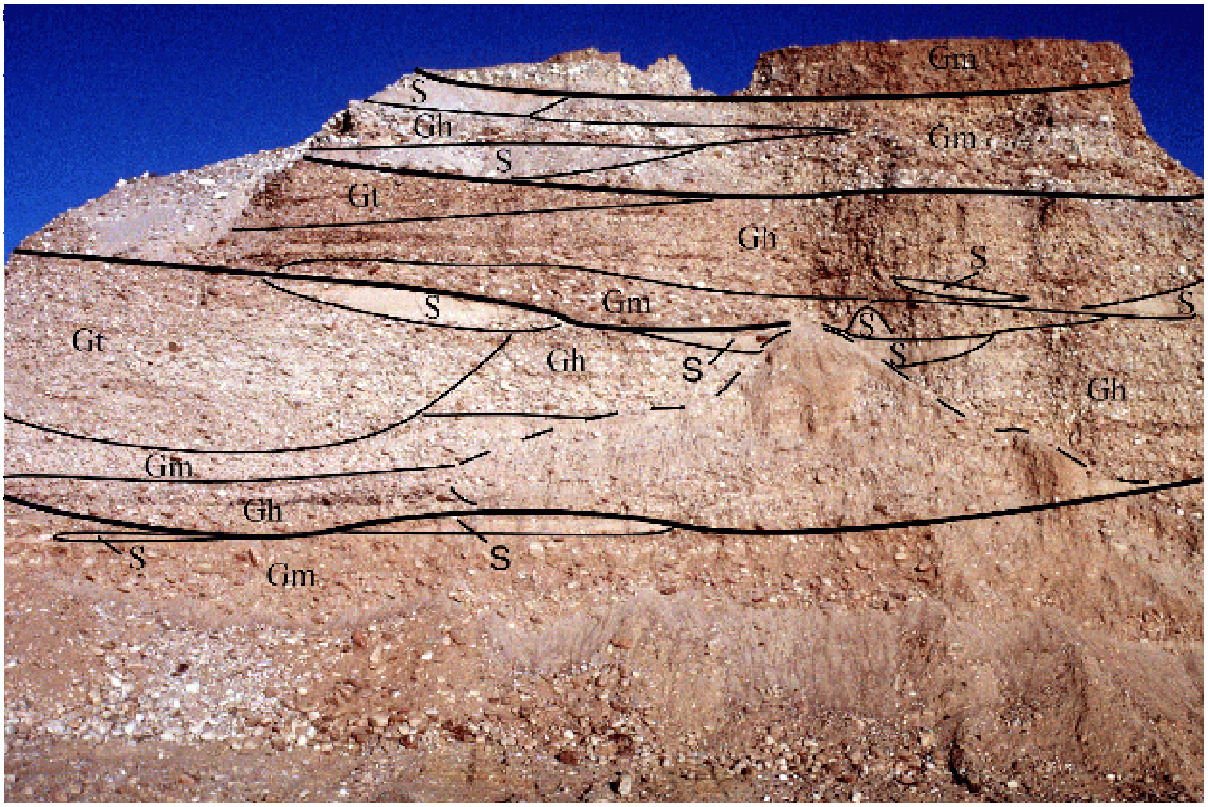
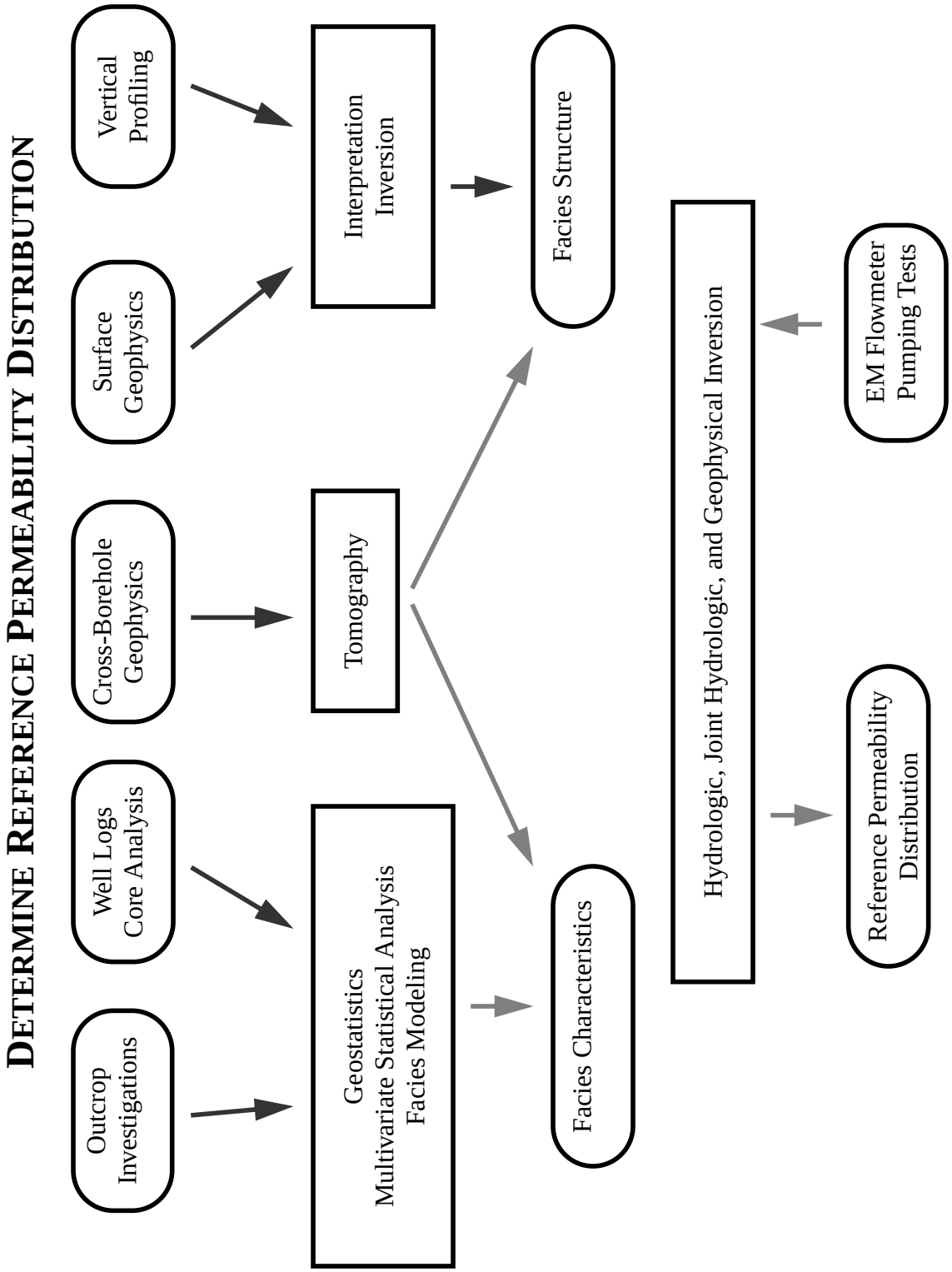
Cross hole radar tomography in an alluvial gravel deposit: The Boise Hydrogeophysical Research Site

William P. Clement
CGISS
Boise State University


Gm
S
Gh
Gm
S
Gt
Gh
S
S
Gm
S
S
Gt
Gh
S
S
Gh
Gm
Gh
S
S
Gm


DETERMINE REFERENCE PERMEABILITY DISTRIBUTION
Outcrop Investigations
Well Logs Core Analysis
Cross-Borehole Geophysics
Surface Geophysics
Vertical Profiling
Geostatistics Multivariate Statistical Analysis Facies Modeling
Tomography
Interpretation Inversion
Facies Characteristics
Facies Structure
Hydrologic, Joint Hydrologic, and Geophysical Inversion
EM Flowmeter Pumping Tests
Reference Permeability Distribution

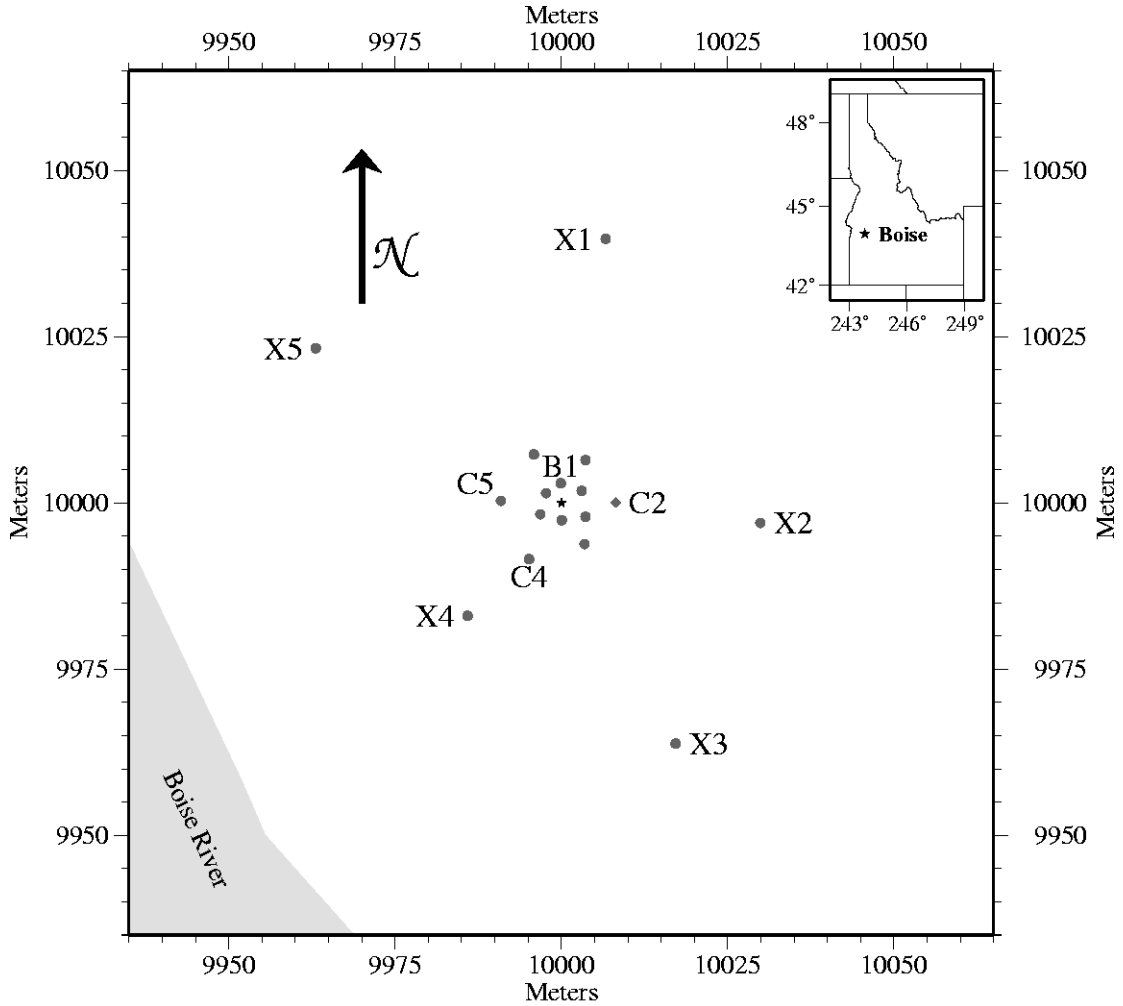
Borehole Methods

Crosshole

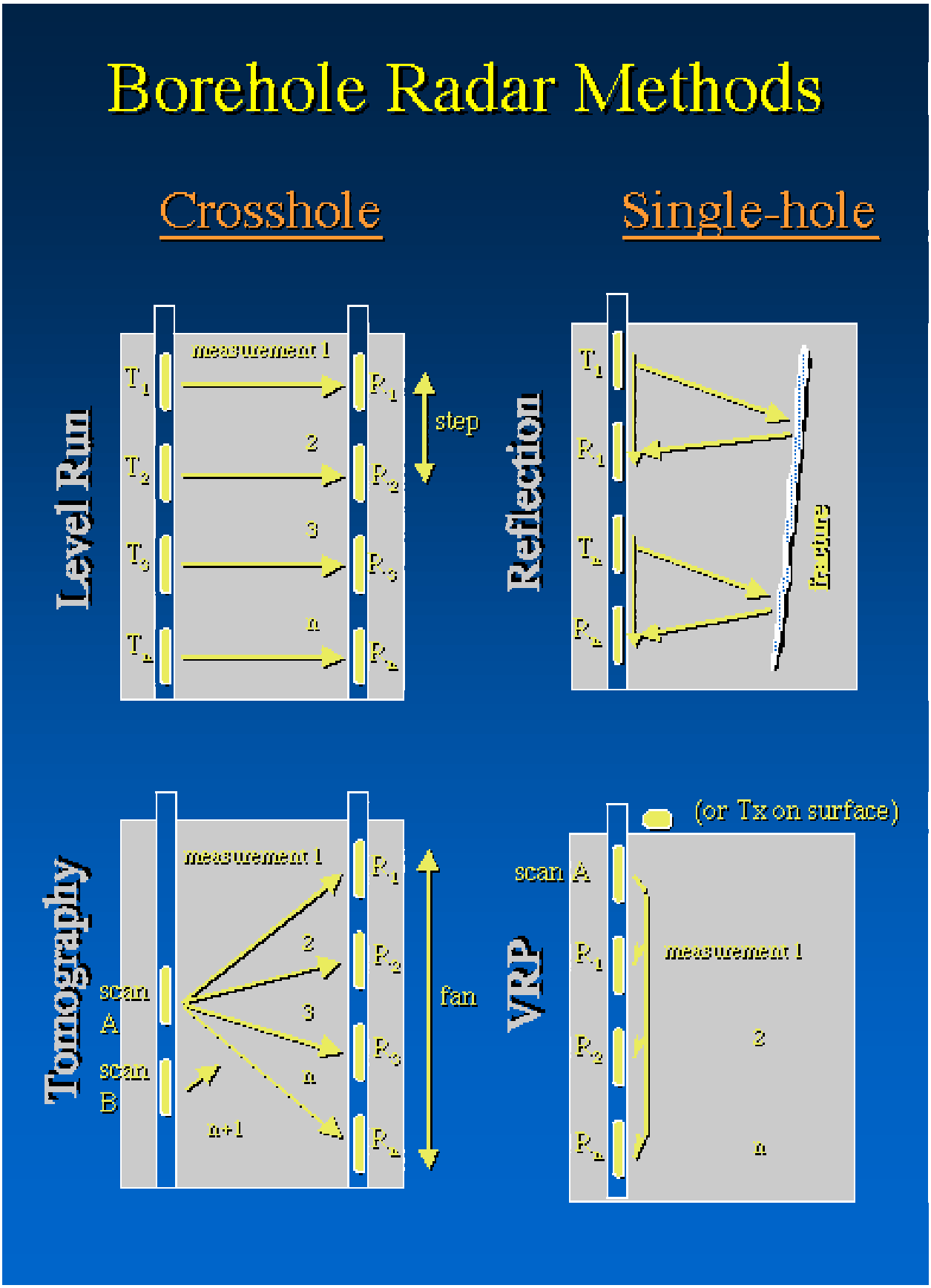
- **Tomography**
- **Reflection Imaging**

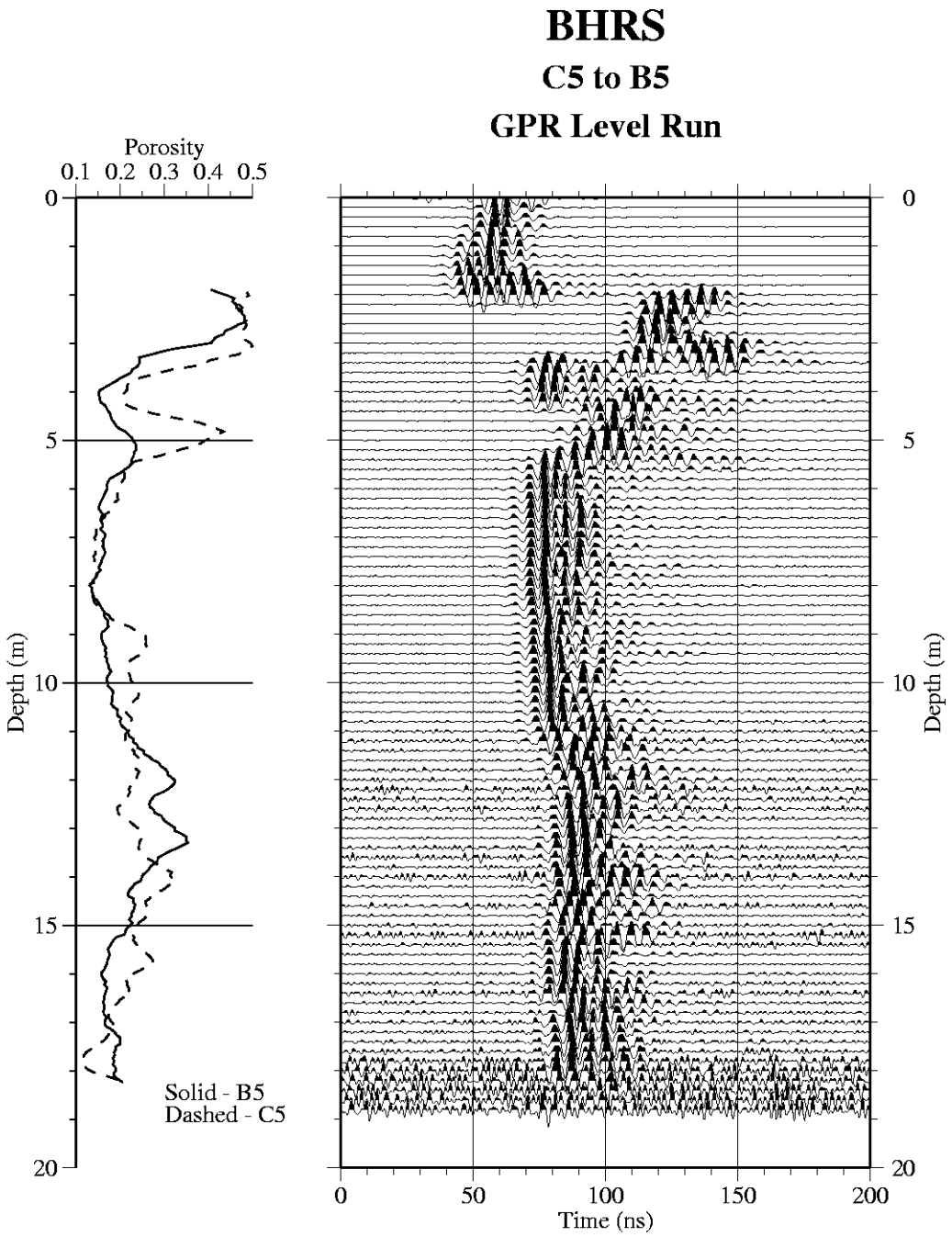
Single borehole

- **VRP/VSP**
- **RVSP**
- **Single hole reflection**



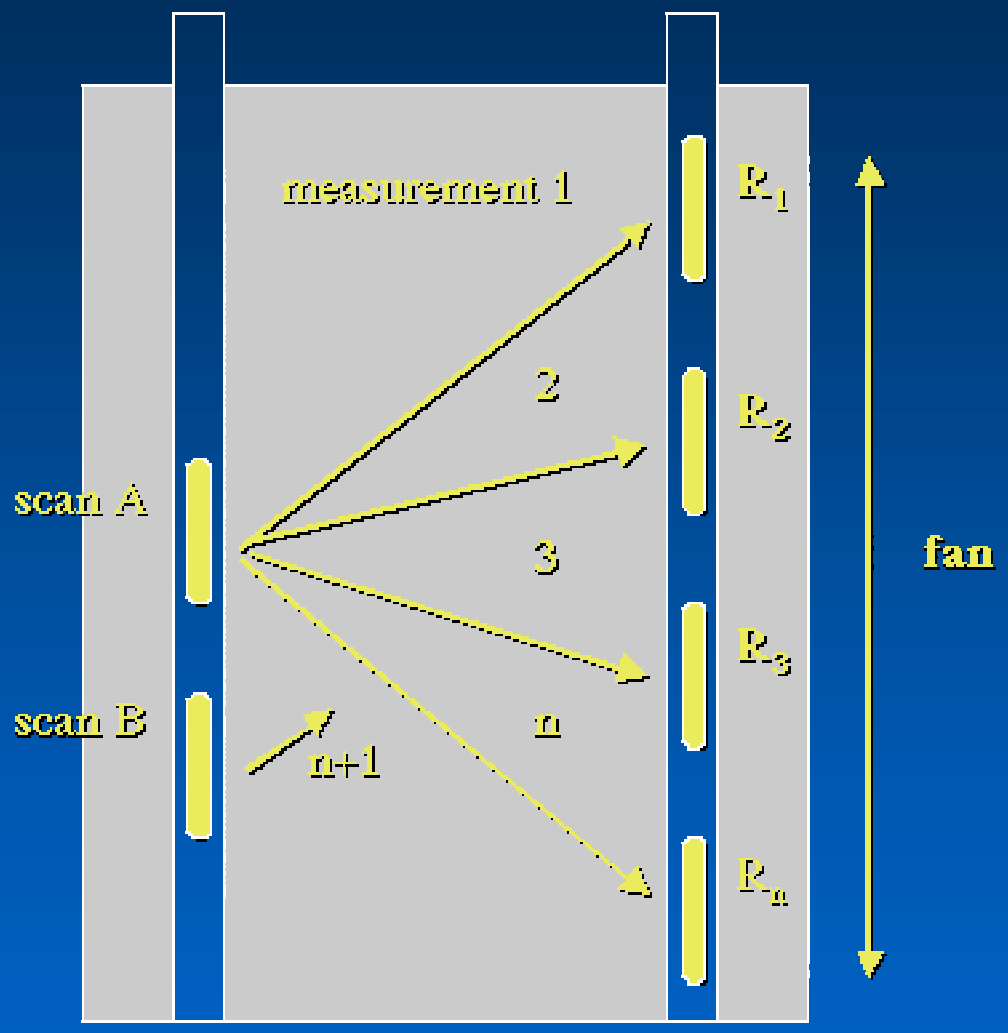
Site map of the BHRS


Borehole Radar Methods
Crosshole
Single-hole
Level Run
measurement 1
2
3
n
step
Reflection
fracture
Tomography
measurement 1
2
3
n
n+1
scan A
scan B
fan
VRP
(or Tx on surface)
scan A
measurement 1
2
n



GMT Jan 15 15:16:30 2000 URISP/Level_ramac/Level_log.gmt

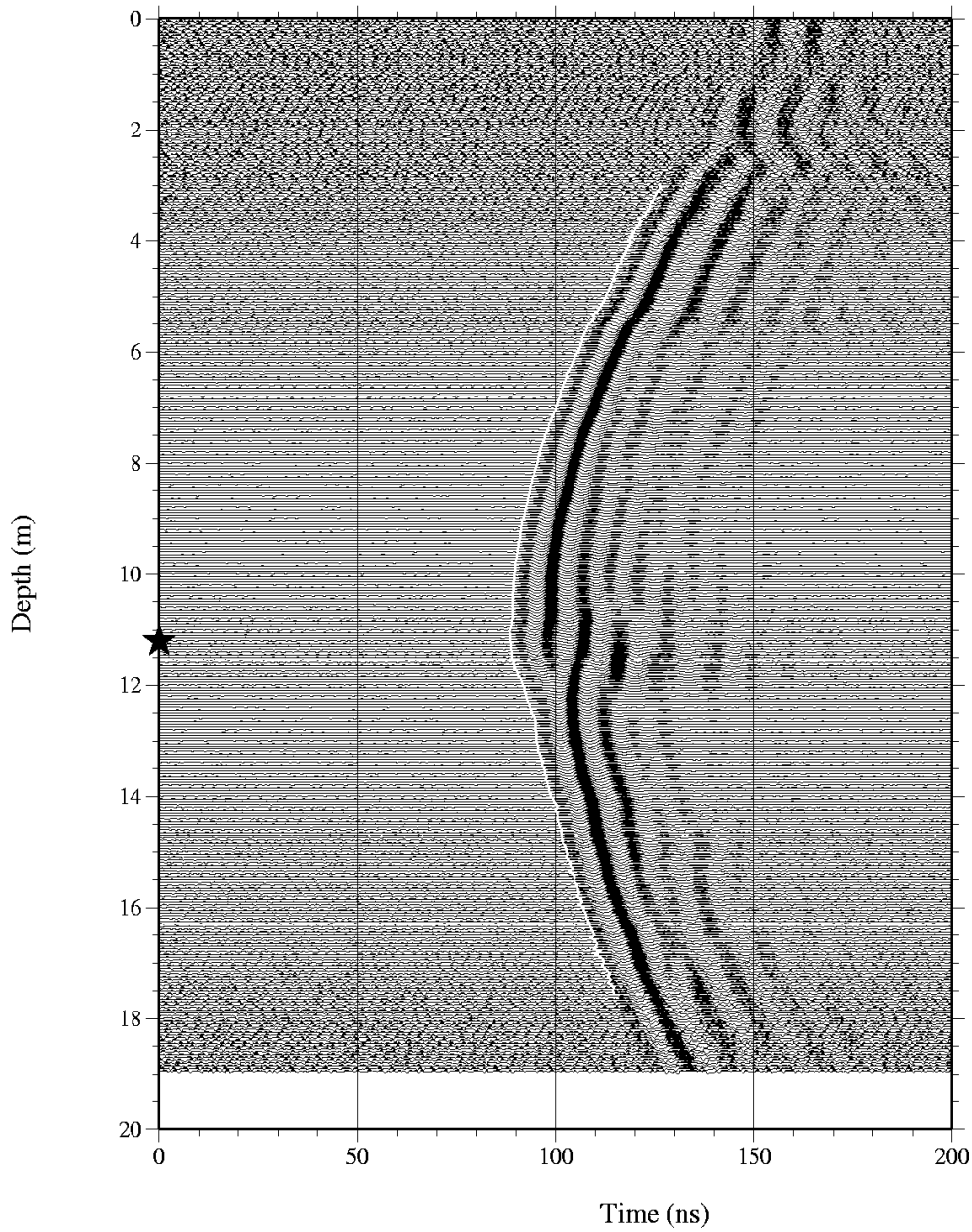
Tomography Acquisition



BHRS

Crosshole Profile

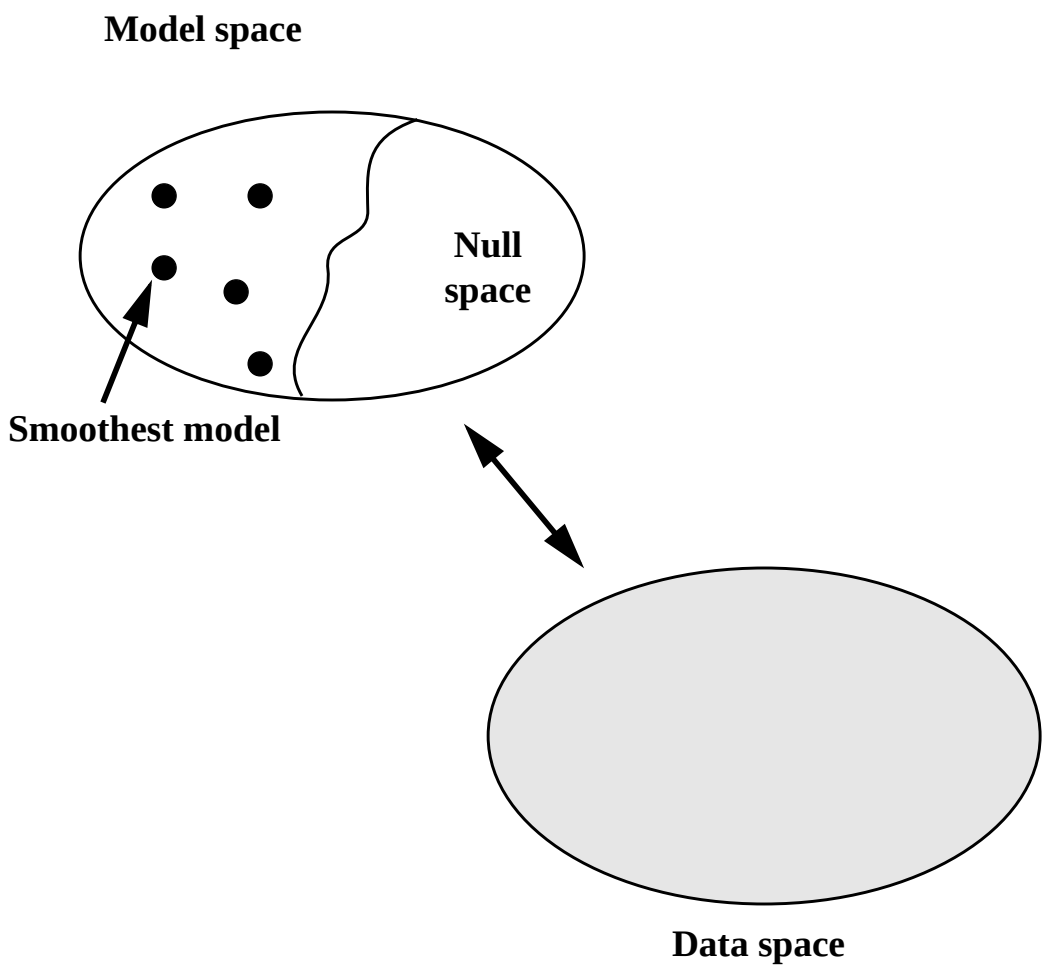
Well C6 to C5



Source at 11.2 m depth

GMT Jan 18 14:59:22 2000 billc/URISP/1998/Mala/Crosshole/Cross.gmt

Inverse Modeling



Inversion Methods

Occam

- **Simplest model that fits data**
- **Regularization**
- **Smooth**
- **Flat**

Bayesian

- **Incorporates prior knowledge**
- **Geostatistics**
- **VRP/VSP**
- **Well logs**
- **Geology**
- **Updating**
- **Use new information**

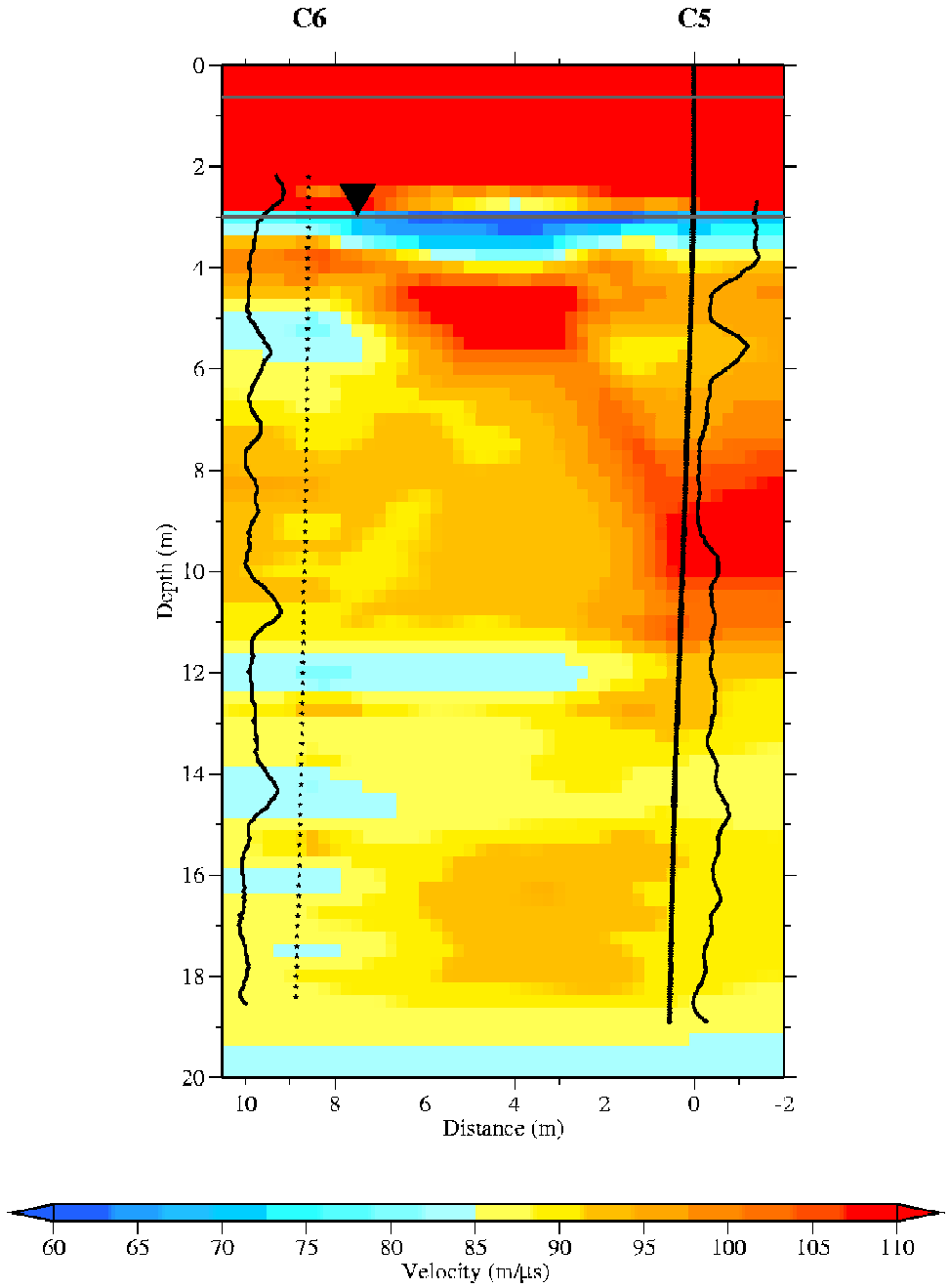
BHRS GPR Tomography

Curved Rays

Regularization - flatness (5, 1)
Velocity models (ref, init)

0.25 ns picking error
0.25 m grid spacing

10 Tomographic iterations
25 LSQR iterations

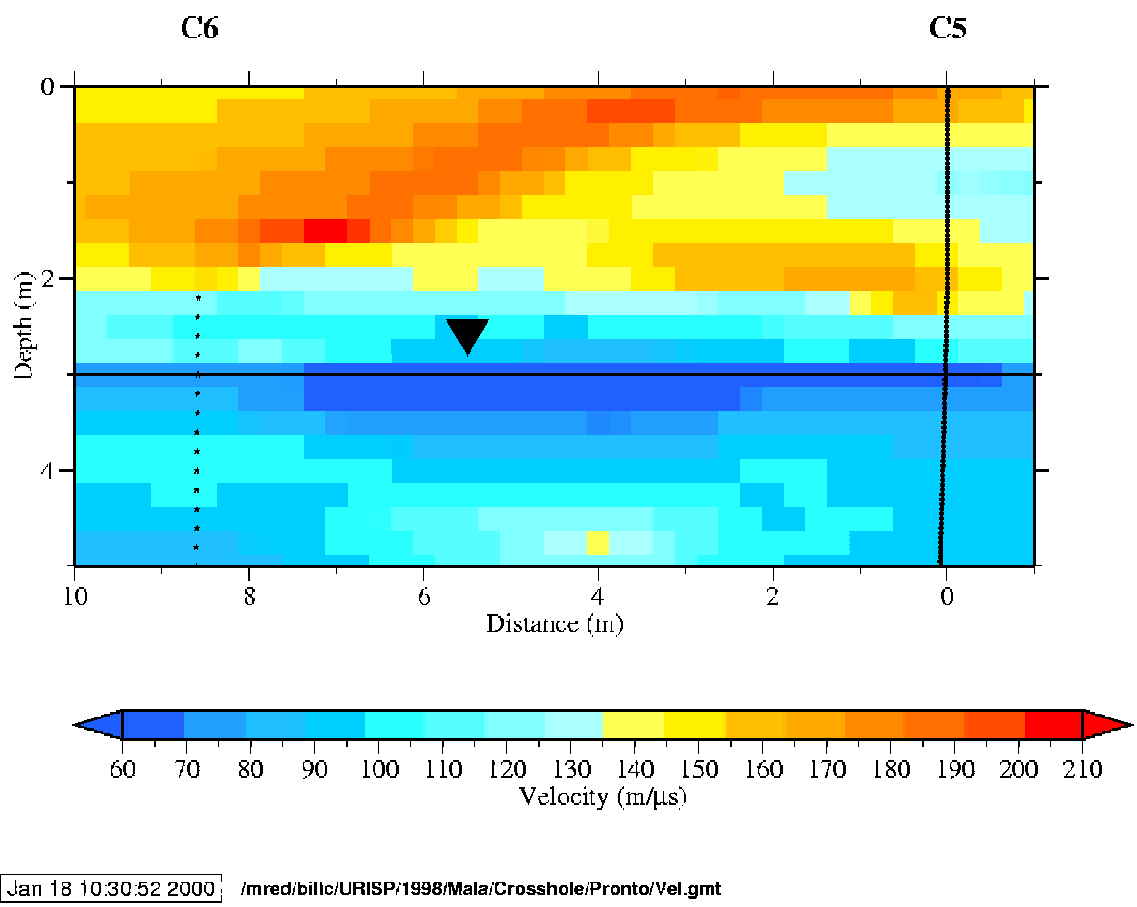


GMT Jan 18 10:30:56 2000 URISP/1998/Mala/Crosshole/Pronto/Vel_pore.gmt

BHRS GPR Tomography

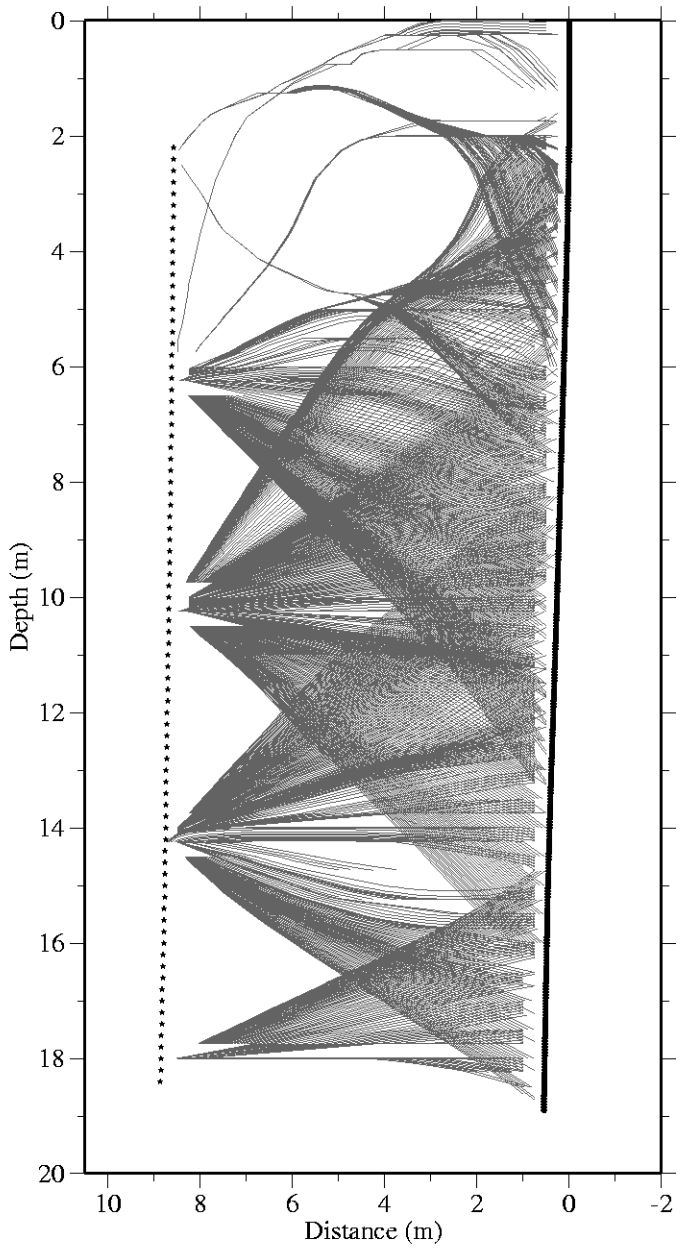
Curved Rays

Regularization - flatness (5, 1)	0.25 ns picking error	10 Tomographic iterations
Velocity models (ref, init)	0.25 m grid spacing	25 LSQR iterations



GPR Tomography

Curved rays

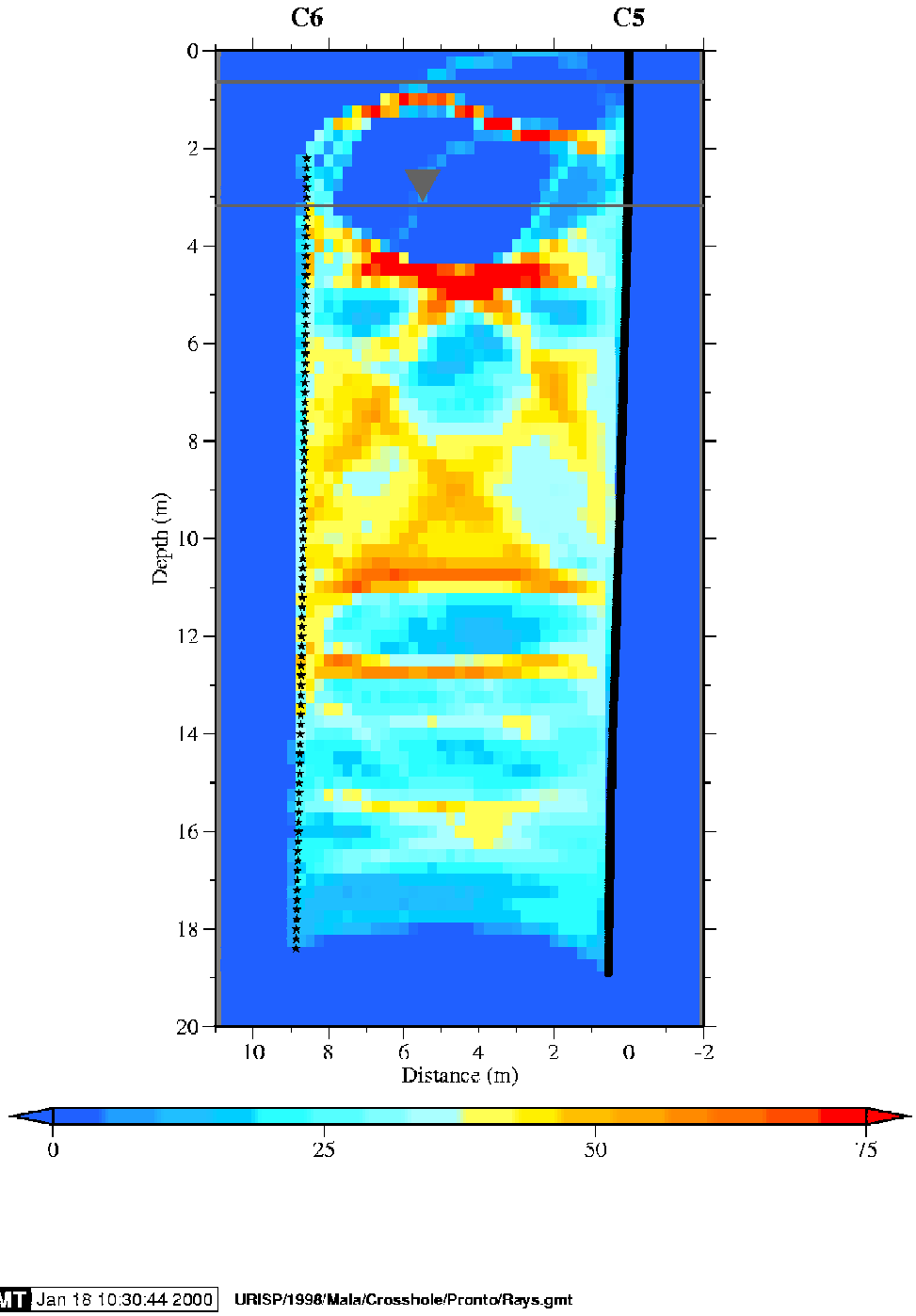


GMT Jan 18 10:30:51 2000 /home/billc/URISP/1998/Mala/Crosshole/Pronto/Trace.gmt

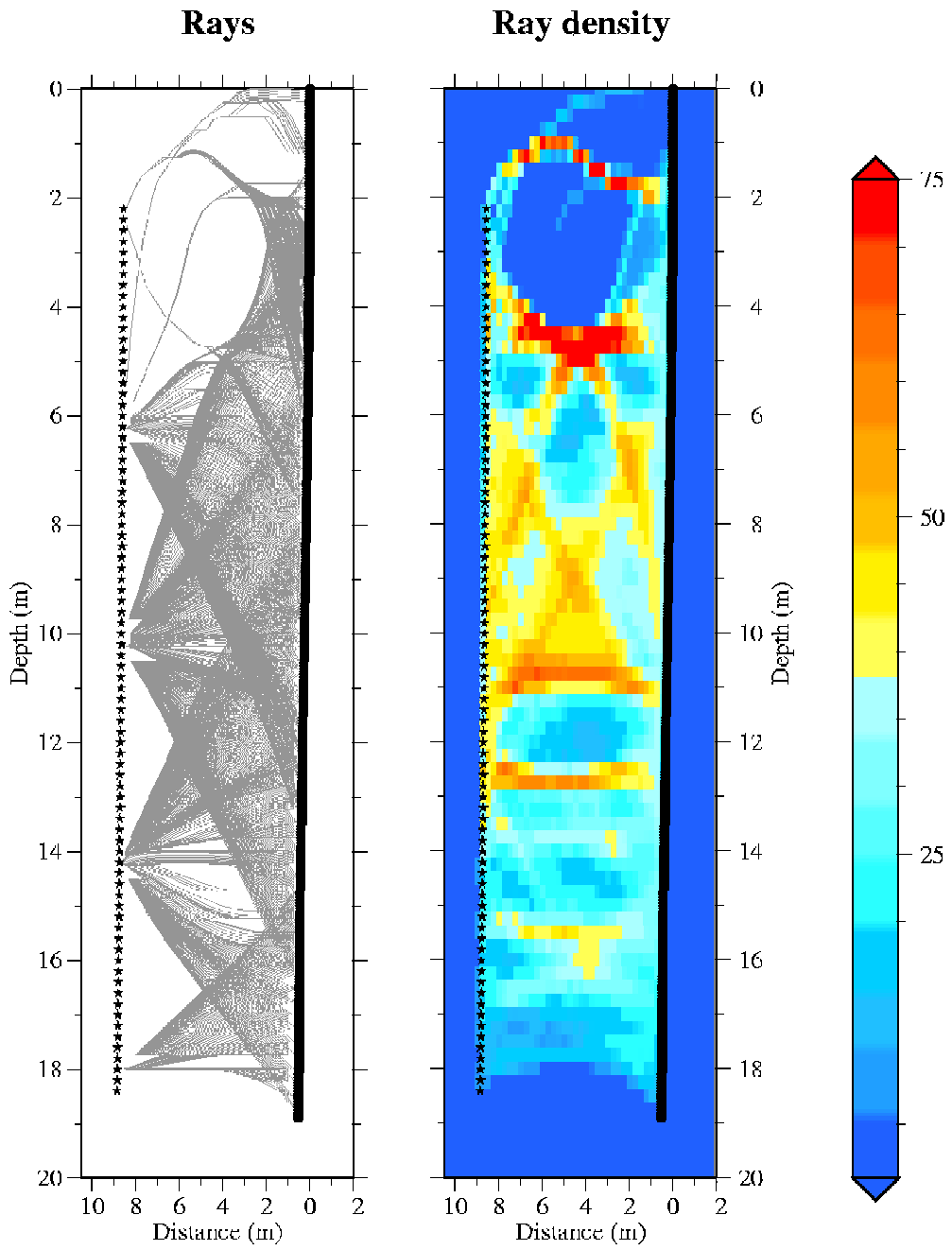
BHRS GPR Tomography

Curved Ray

Ray density



BHRS GPR Tomography

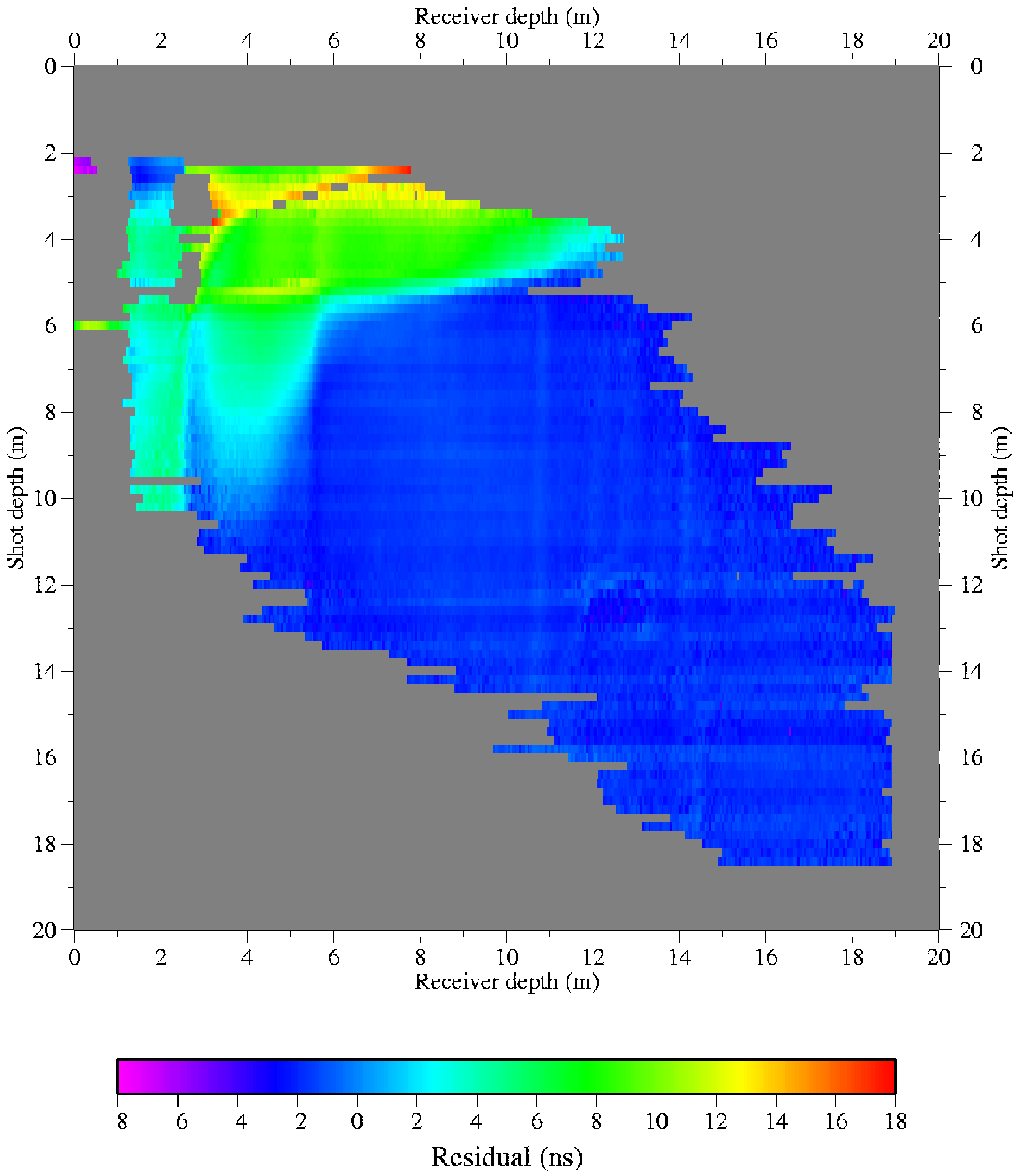


GMT Jan 18 10:30:45 2000 Error/Pronto/RayTrace.gmt

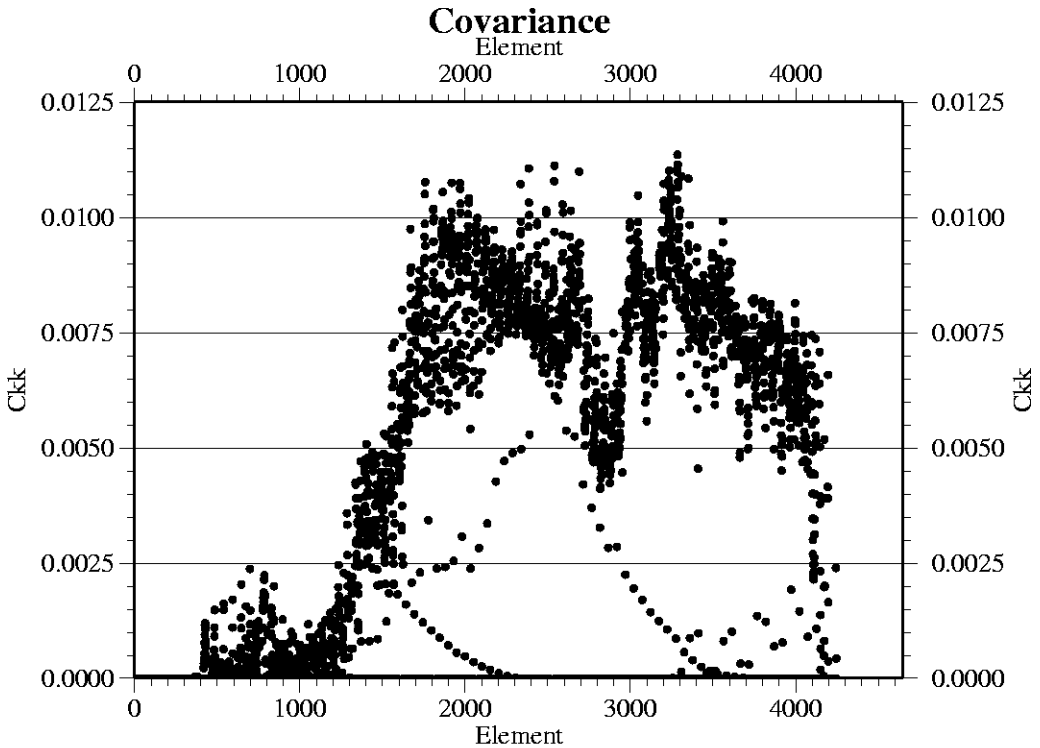
C6 -> C5

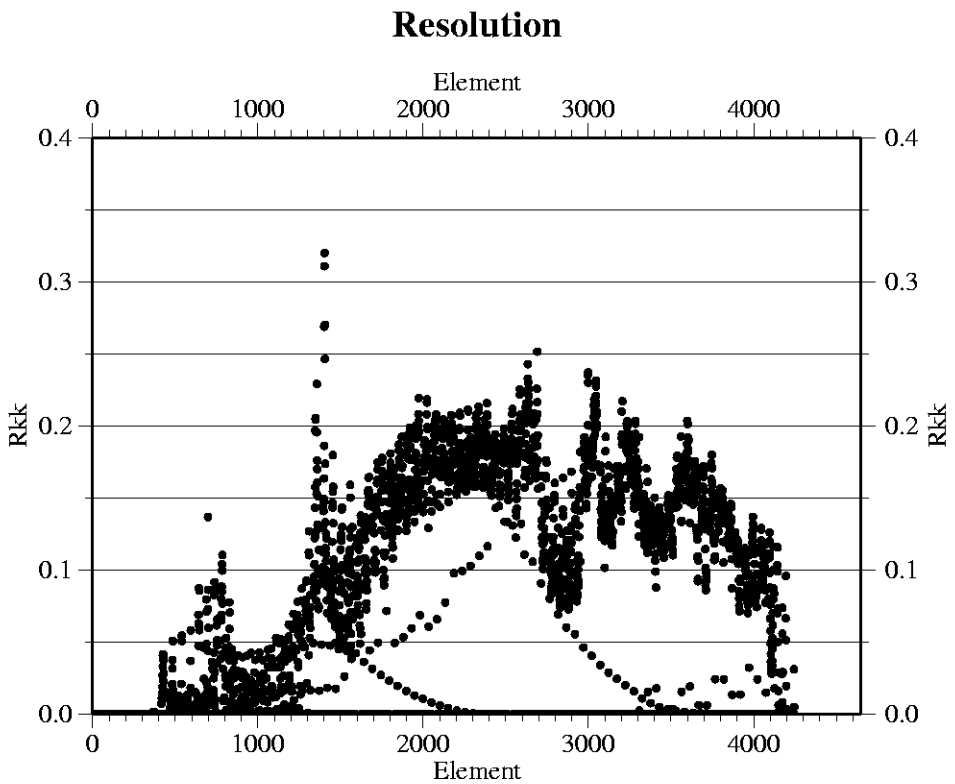
Curved ray

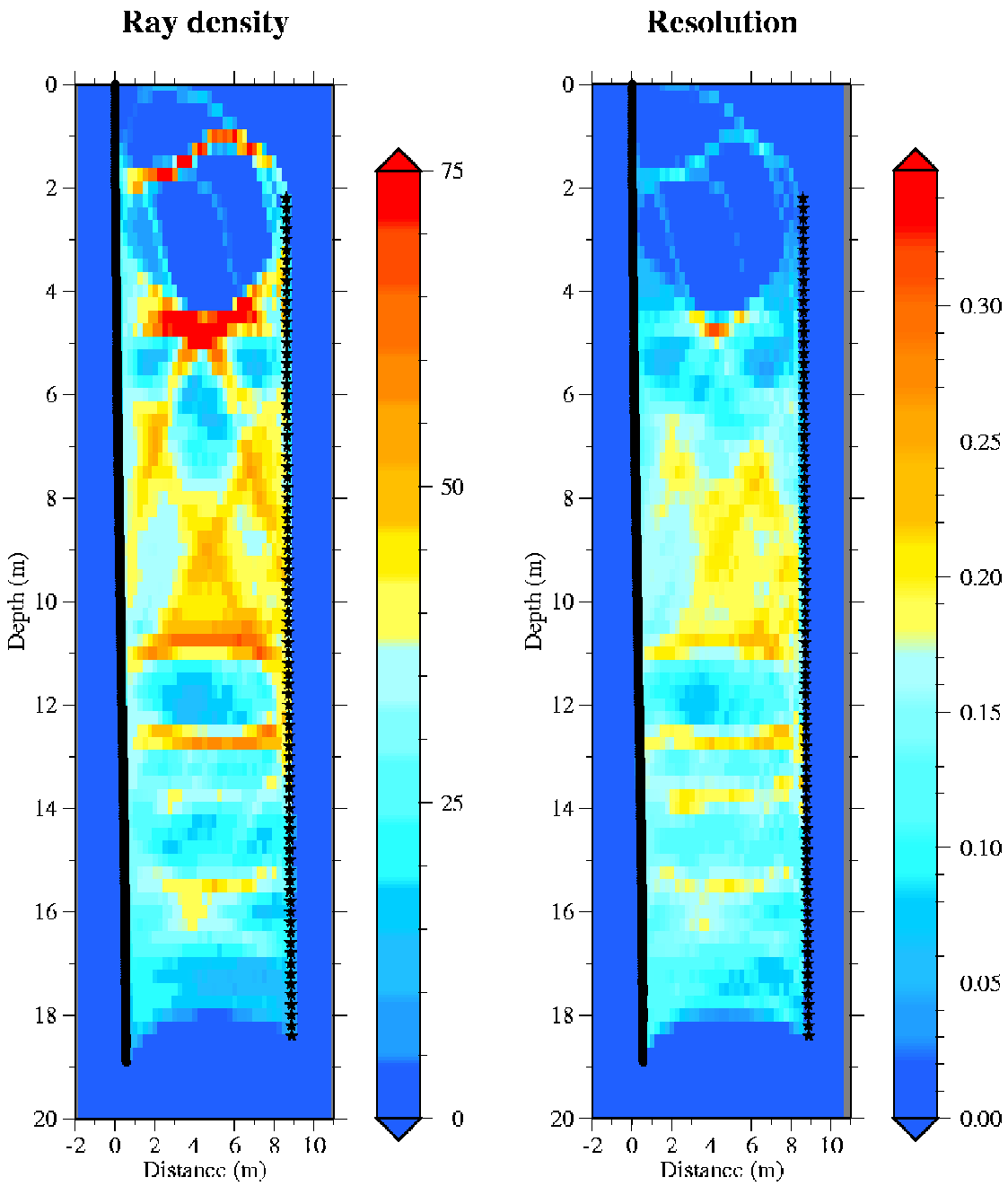
Travel time residuals (ns)

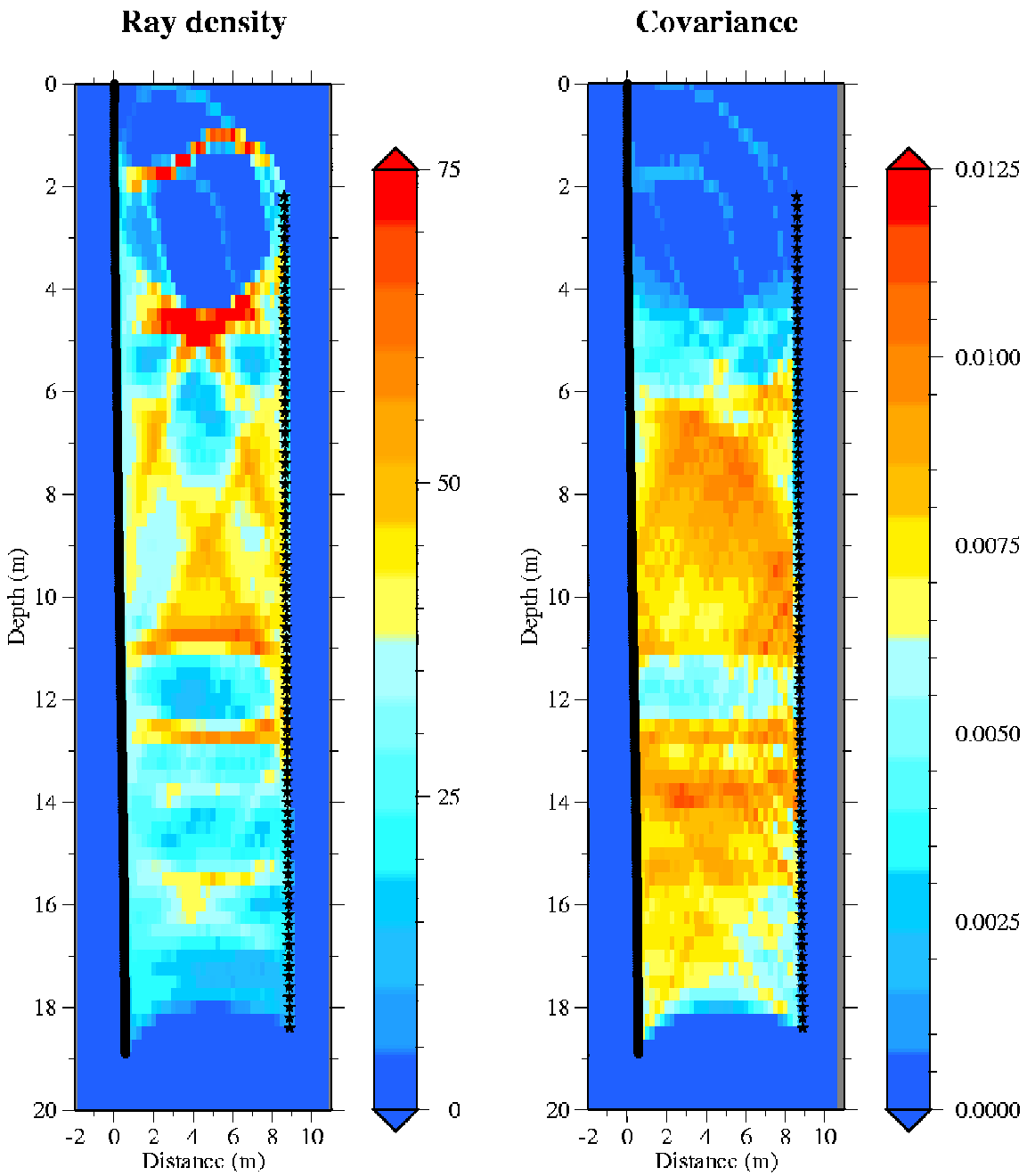


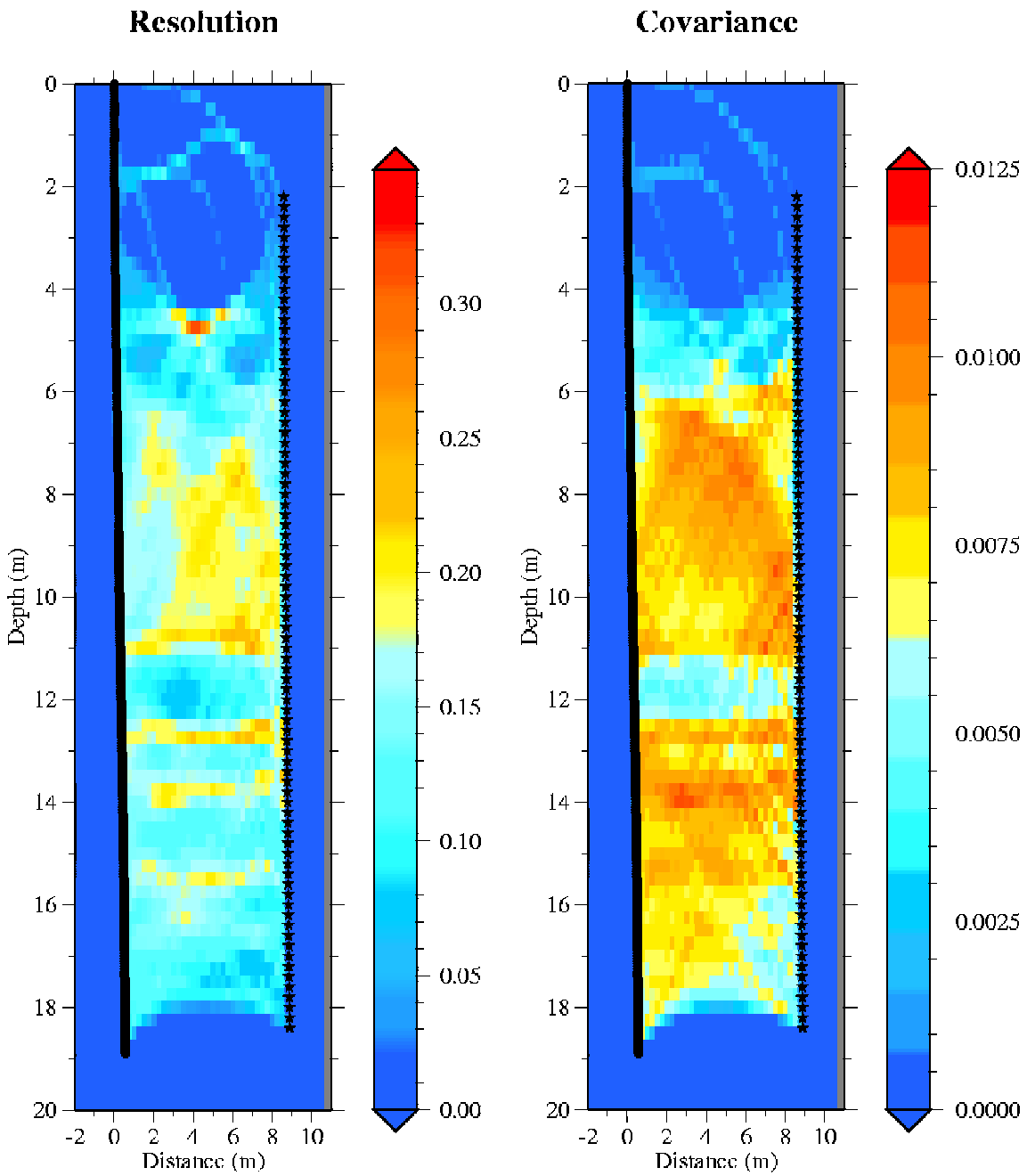
GMT Jan 18 10:30:48 2000 URISP/1998/Mala/Crosshole/Residual.gmt


Covariance
Element
0
1000
2000
3000
4000
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000
Ckk


Resolution
Element
0
1000
2000
3000
4000
0.4
0.3
0.2
0.1
0.0
Rkk


Ray density
Resolution
Depth (m)
Distance (m)
0
2
4
6
8
10
12
14
16
18
20
-2
0
2
4
6
8
10
75
50
25
0
0.30
0.25
0.20
0.15
0.10
0.05
0.00


Ray density
Covariance
Depth (m)
Distance (m)
0
2
4
6
8
10
12
14
16
18
20
-2
0
2
4
6
8
10
75
50
25
0
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000


Resolution
Covariance
Depth (m)
Distance (m)
0
2
4
6
8
10
12
14
16
18
20
-2
0
2
4
6
8
10
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.0125
0.0100
0.0075
0.0050
0.0025
0.0000