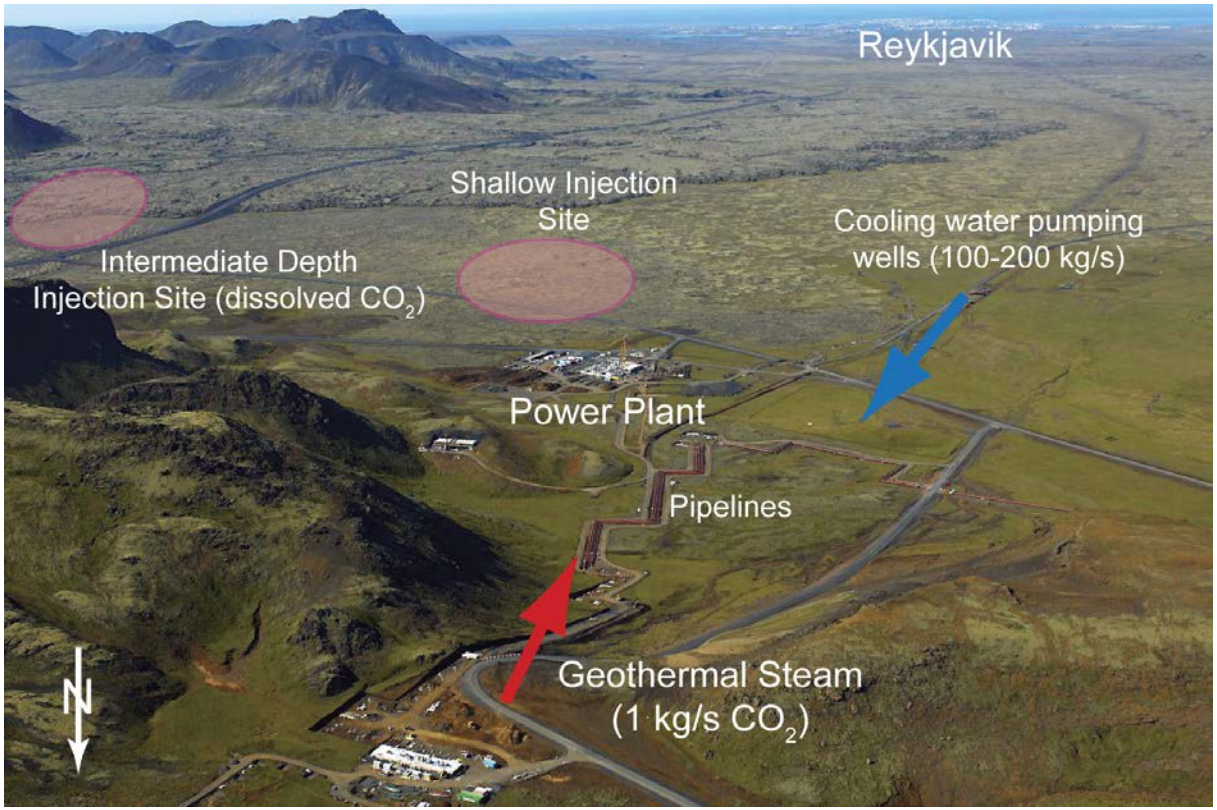

Advanced 3D Geophysical Imaging Technologies for Geothermal Resource Characterization

April 22-25, 2013

Principal Investigator: Greg Newman, Michael Fehler

Organizations: LBL & MIT

Track Name

Collaborators

Project Participants and Collaborators:

Lawrence Berkeley National Laboratory
Massachusetts Institute of Technology
Iceland GeoSurvey (ÍSOR);
Reykjavík University;
Uppsala University;
TerraGen (Operator of the Coso Field);
Icelandic Power Companies

Project objectives

- Develop improved geophysical imaging method for characterizing subsurface structure, identify fluid locations, and characterize fractures
- Obtain the maximum amount of information from seismic and electromagnetic data by developing new joint inversion methodology
- Apply the new method to four sites
  - Improve methods by application to real data from differing environments
  - Demonstrate applicability of methods

Scientific/Technical Approach

- Multi-steps for combined analysis
  - Individual analysis of geophysical datasets for 4 sites
    - Integrated interpretation
  - Iterative analysis using output of one method as input to another
    - MT <-> Seismic
  - Joint Imaging for common structure
- Analysis methods used
  - MT inversions for resistivity
  - Double-difference tomography (DDT) using micro-earthquake sources
  - Fully coupled elastic inversion

Four Regions Being Studied

- Krysuvik & Hengill Reykjanes area, Iceland
  - Several producing geothermal fields
  - Collect new MEQ data, leverage with existing MEQ data from ISOR Network & MT data
- Krafla volcano, Iceland
  - Producing Geothermal field
  - First Iceland Deep Drilling Project (IDDP) well
  - Use existing MEQ and MT datasets
- Coso Hot Springs, USA
  - Producing geothermal field
  - Analyze existing MEQ and MT data

Krafla

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Early in FY13	Krafla Model Appraisal (3D resistivity cube)	March FY13
Fall FY12	Krafla Joint MEQ-MT Analysis (initial results)	March FY13

Krafla Magma Chamber

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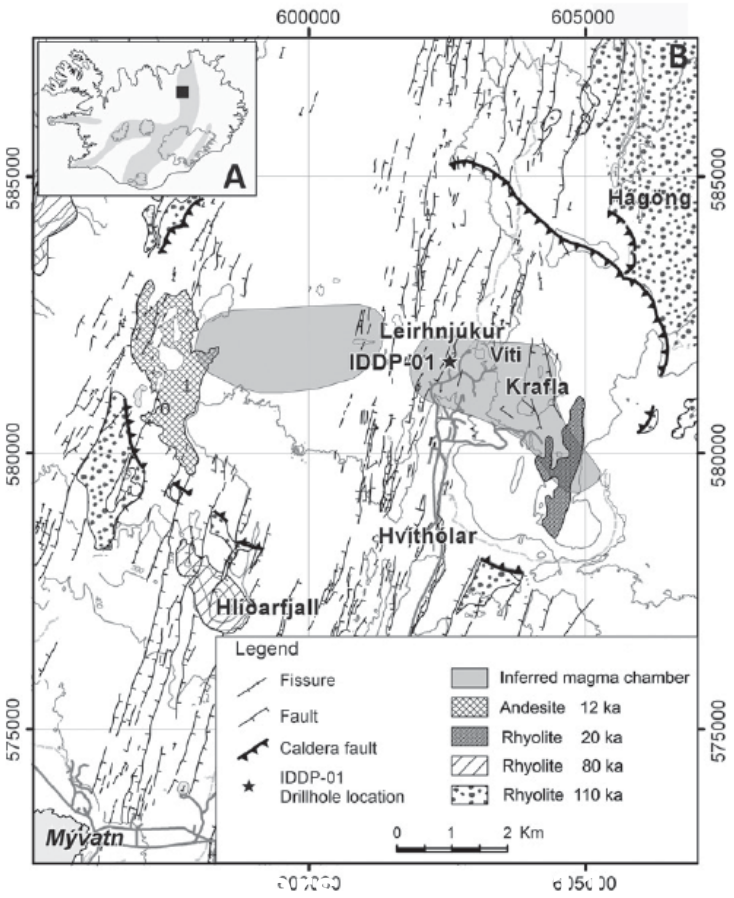
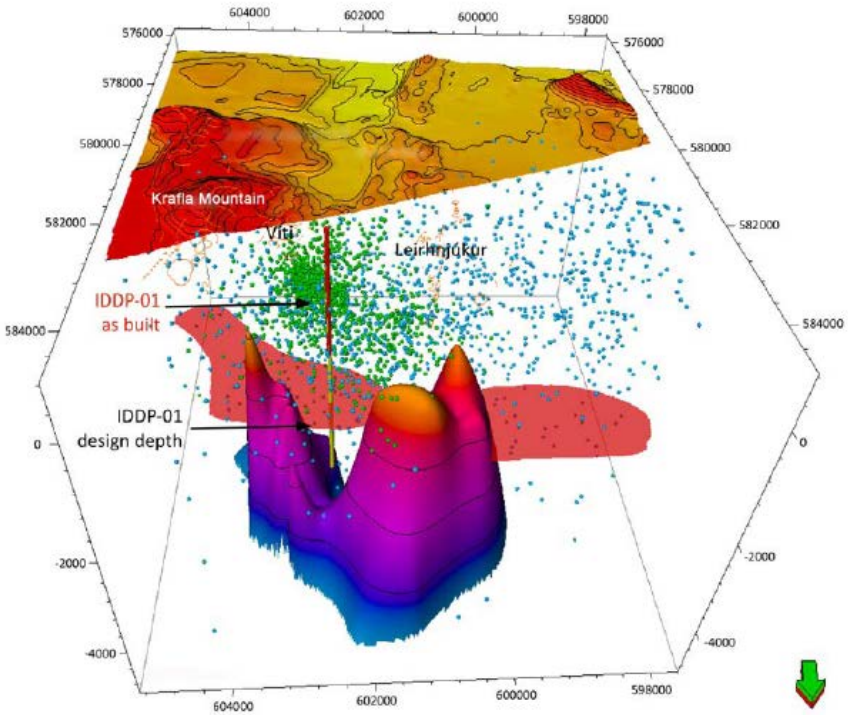


Location of the Well in relation to the Magma Chamber



Krafla – Appraisal of Resistivity Cube

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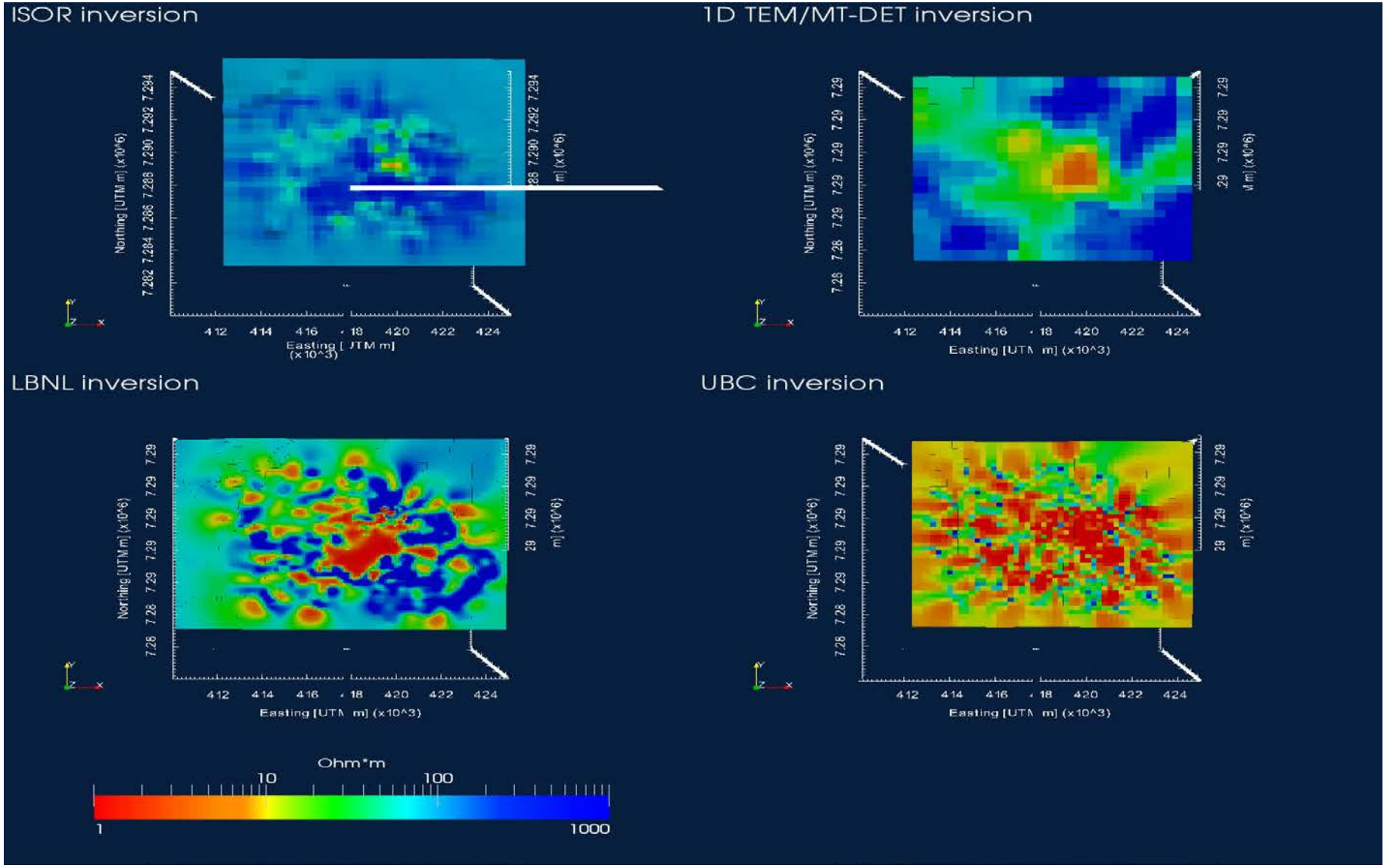


Geothermal zones

- The structures of the zones coincide
  - Resistive core
  - Deep conductive body under NW of IDDP-well

Dissimilarities

- Near surface
  - Very dependent on the initial model
- Edges and data coverage

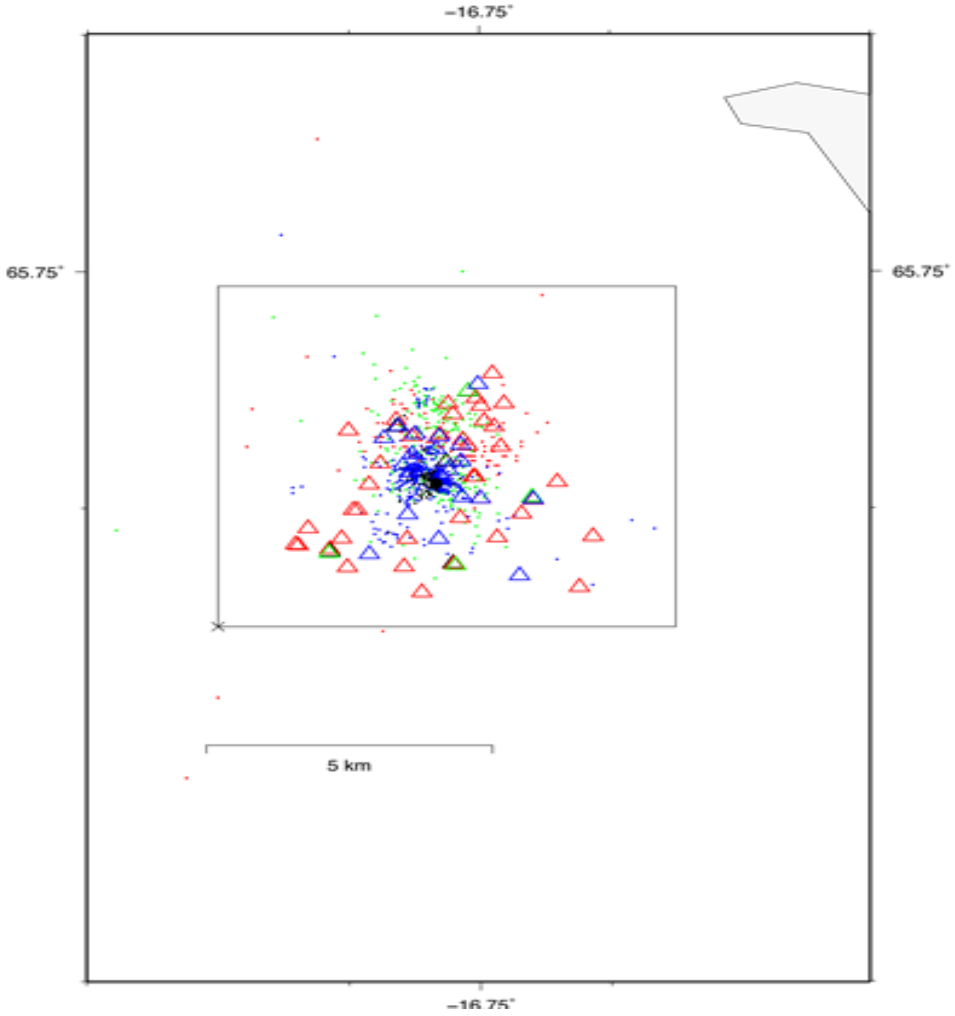
Krafla MEQ Network

Krafla:

Duke
2004-2005
2006-2007

UNC
2004

Borehole network
2008 and 2011



Joint Analysis of Krafla MT-MEQ Data

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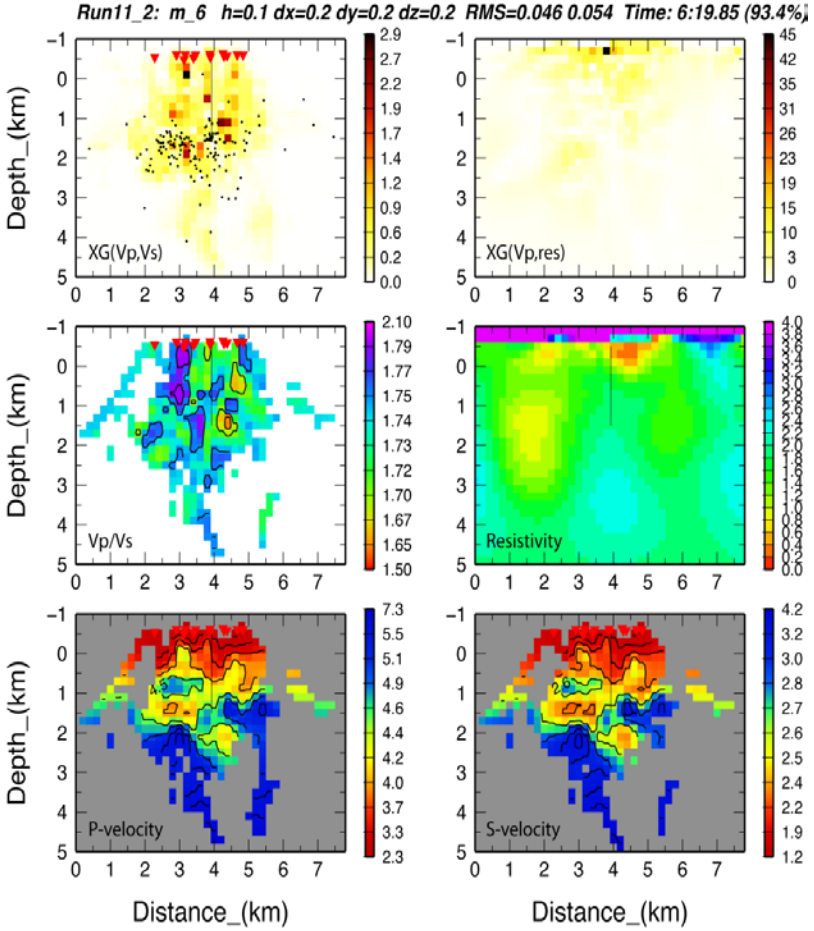
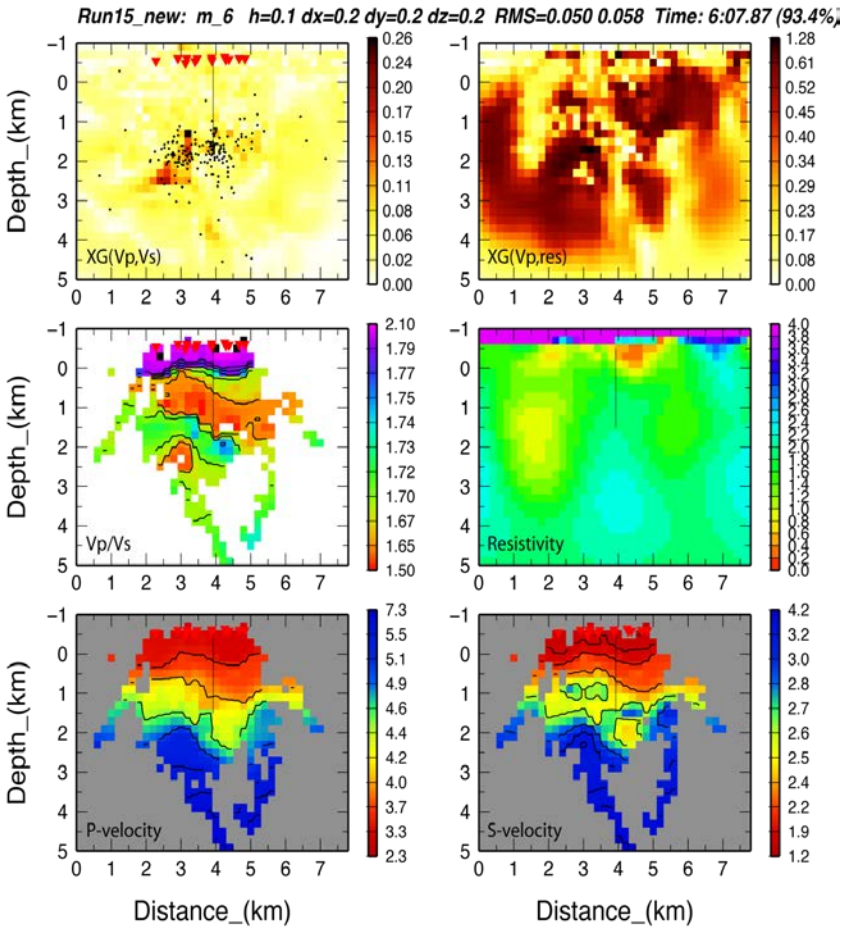
East-West Profile

Not Coupled to Resistivity Structure



Coupled to Resistivity Structure



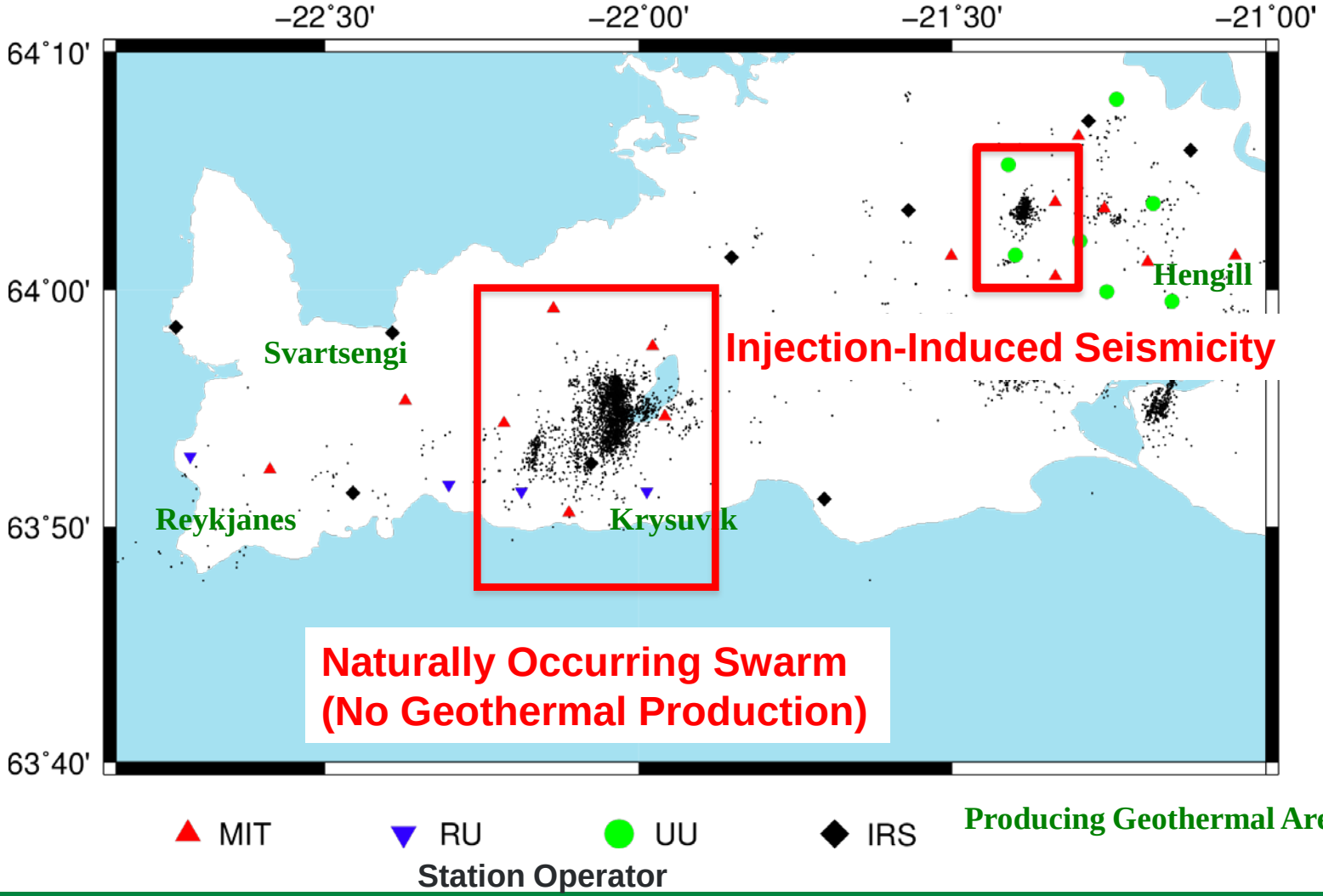
- Sustained operation of 14 station MEQ network in the Reykjanes Peninsula
  - Area includes several producing geothermal power plants
  - Network installed in collaboration with Reykjavik University, ISOR, and University of Uppsala
  - Additional data from Iceland network
  - Over 2.5 years in operation , data quality excellent; operate until fall 2013

Krysuvik – Reykjanes

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
March FY13	Krysuvik Resistivity-Velocity Model (initial results)	March FY13
March FY13	Continuously Operating MEQ Network – Reykjanes Area	March FY13

Reykjanes Peninsula Seismic Network

Seismicity During First Year of Network Operation



P and S Wave Velocity Models -- Krysuvik

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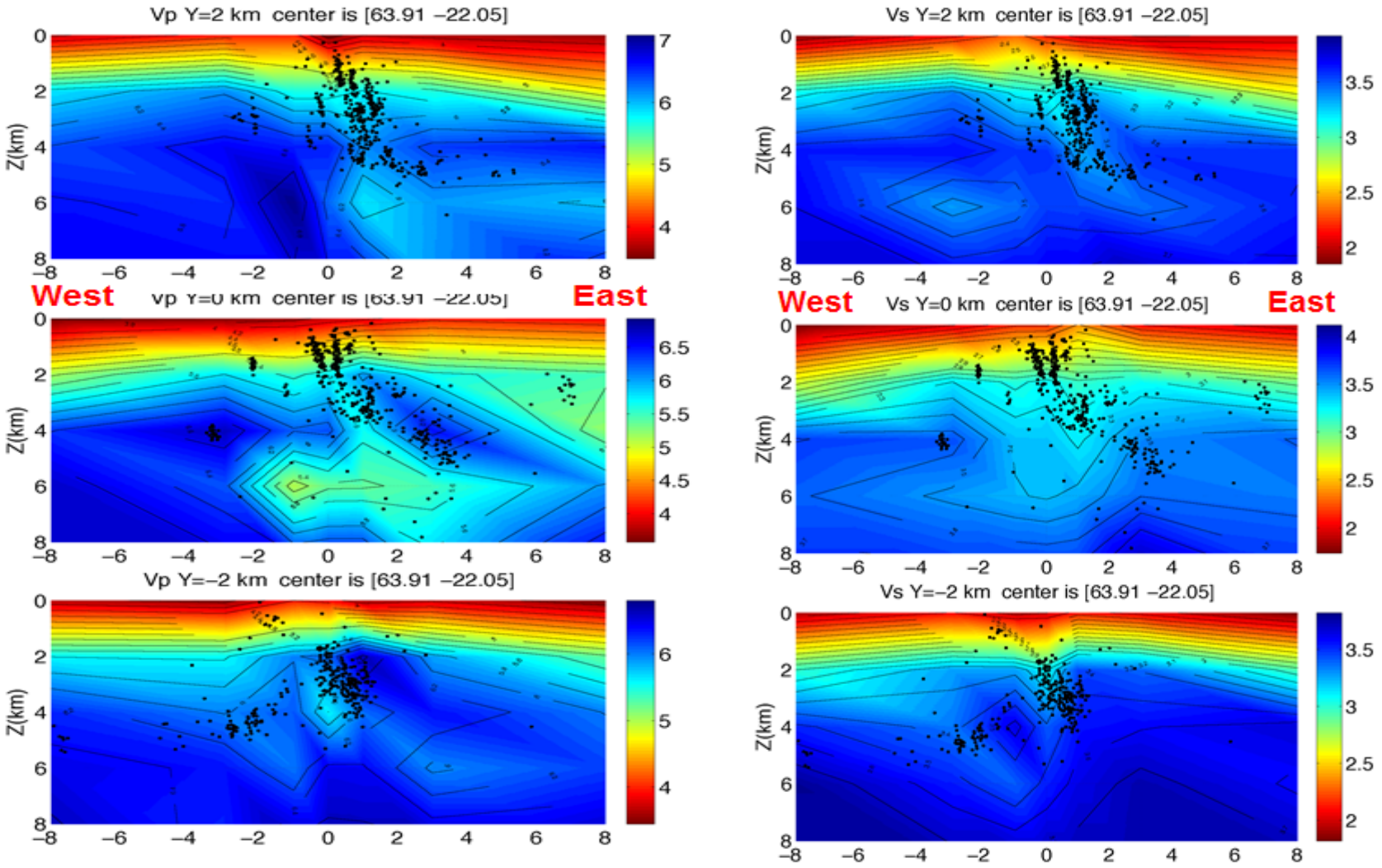
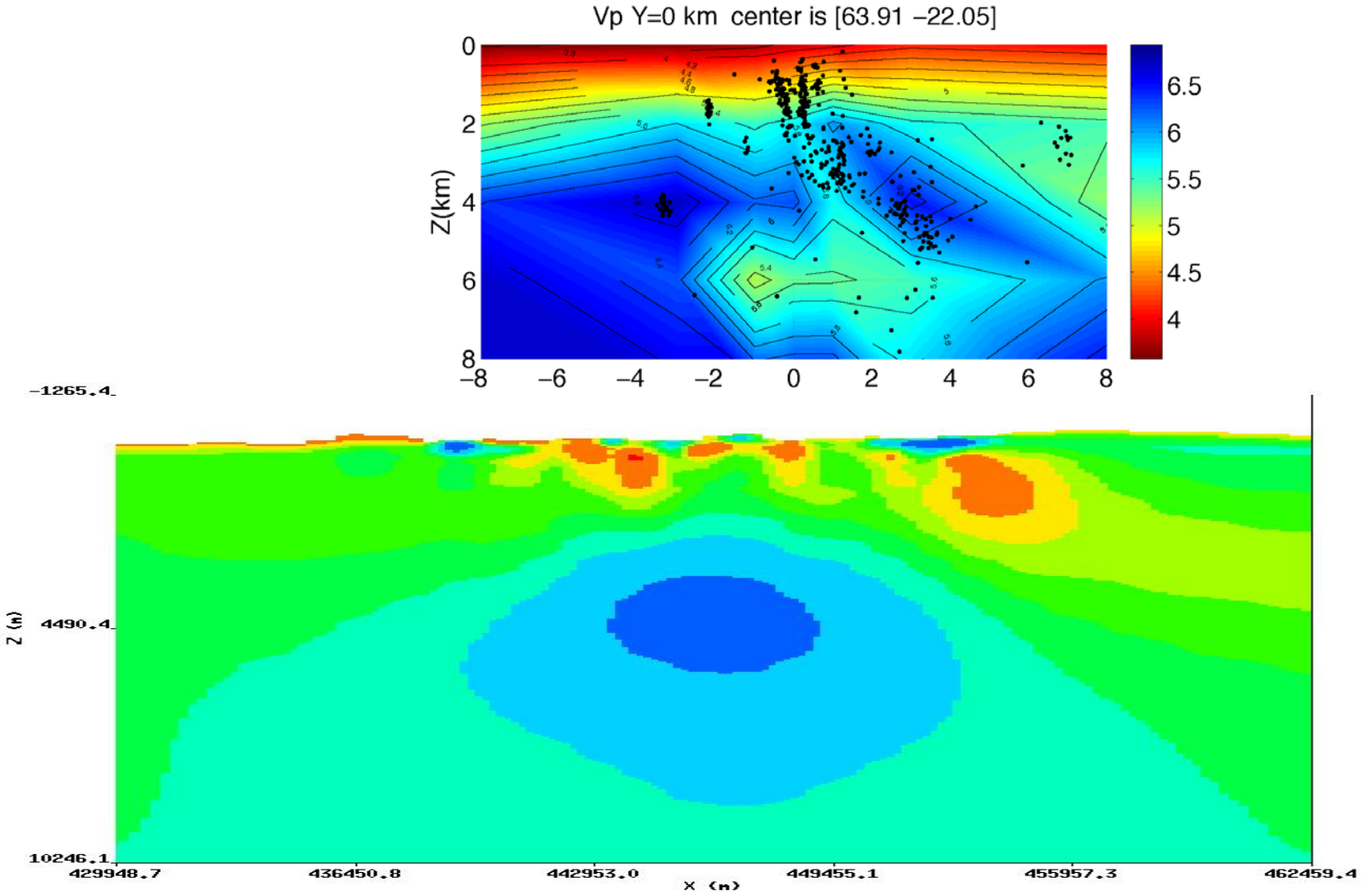
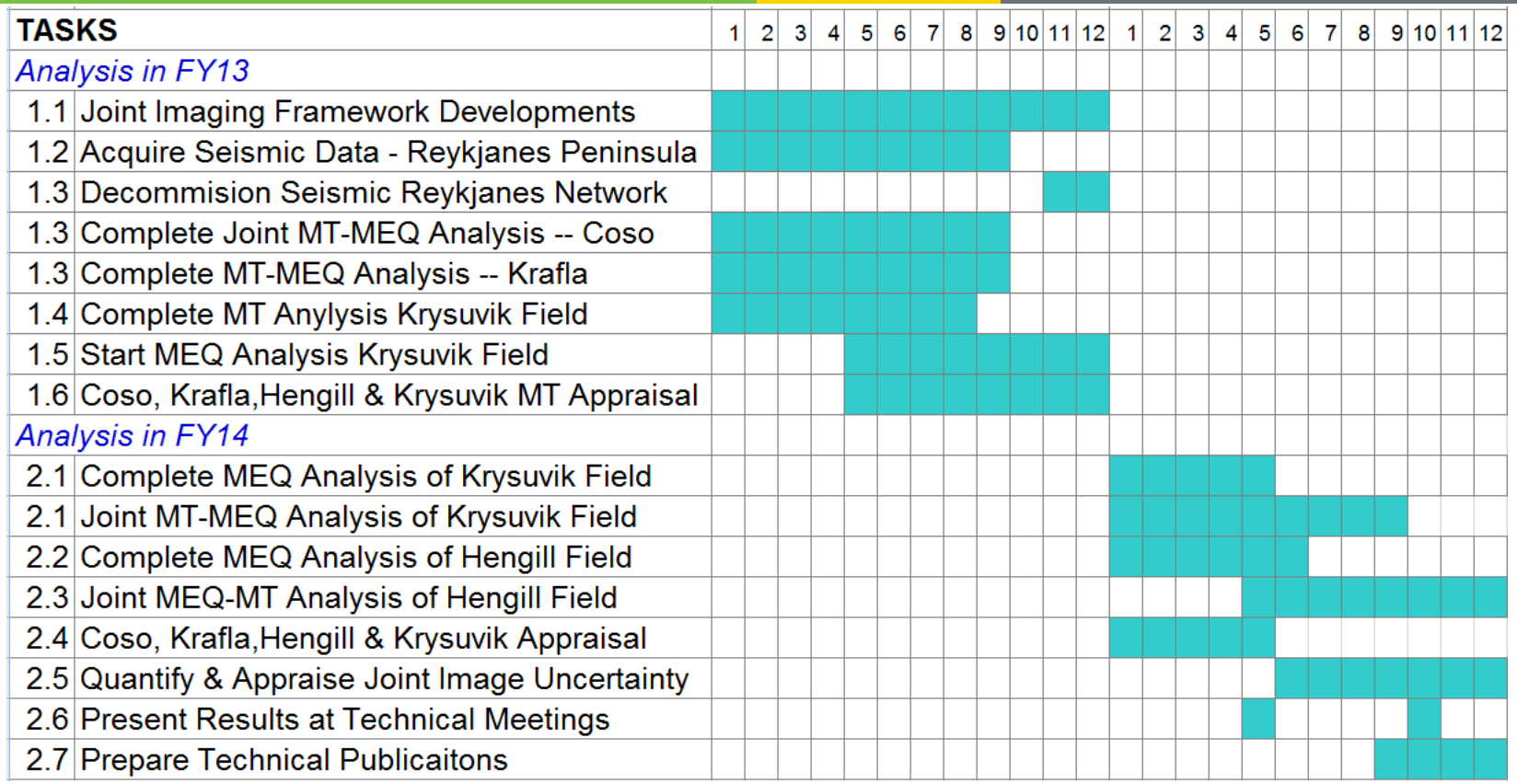


Comparison Vp and Resistivity Krysuvik

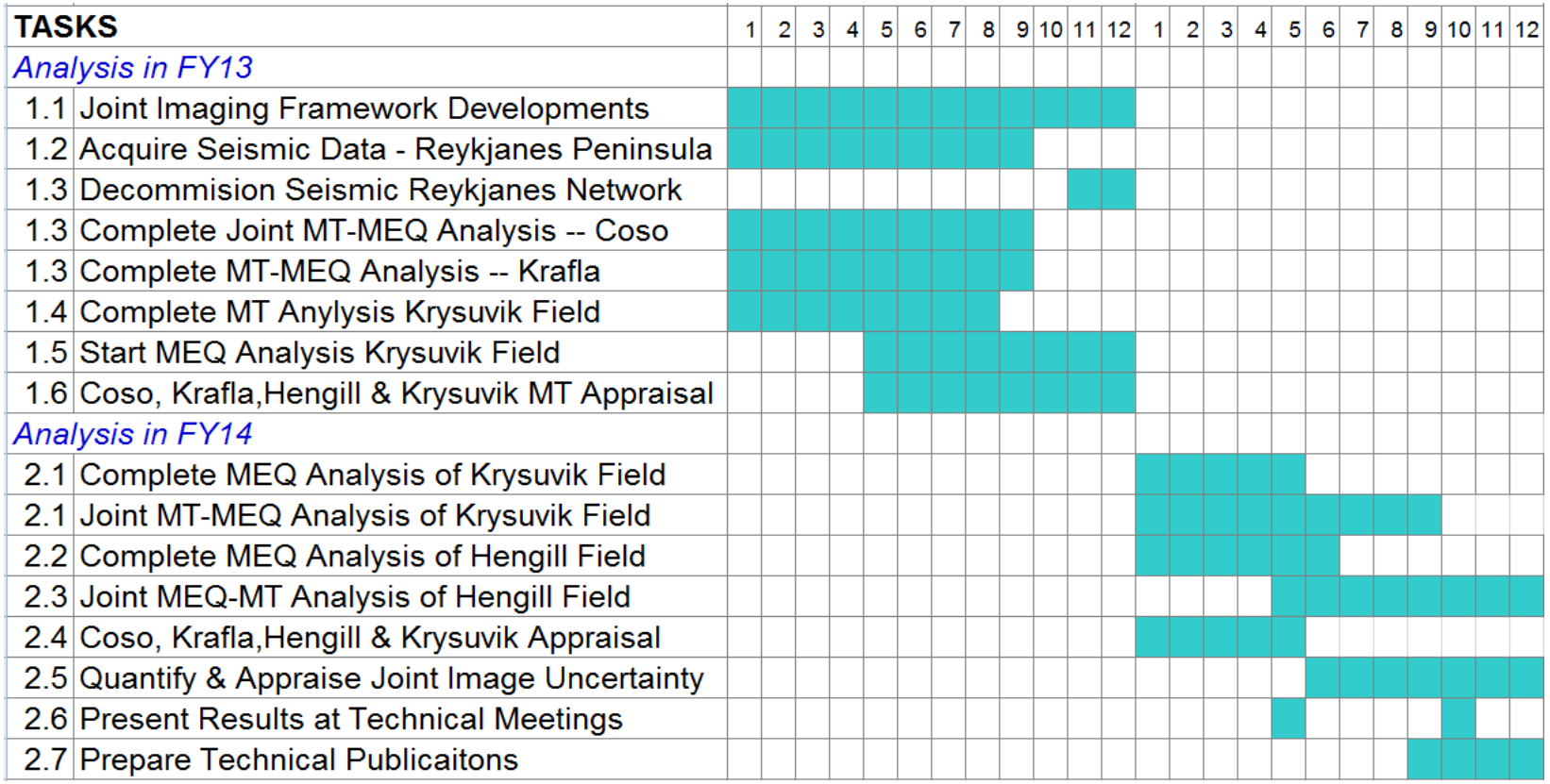


Future Directions



Milestone or Go/No-Go	Status & Expected Completion Date
Krysuvik Baseline MEQ/MT Modeling	MEQ Analysis Stated in February 2013
Pull MEQ Network	September 2013
Krafla Joint MEQ/MT Analysis	June 2013

Future Directions



Milestone or Go/No-Go	Status & Expected Completion Date
Krysuvik Joint MEQ/MT Analysis	June 2014
Hengill MEQ Baseline Analysis	March 2014
Hengill Joint MEQ/MT Analysis	September 2014

Summary

- Correctly-formulated joint inversion has the capability to combine differing datasets to maximize the information obtained about geothermal targets
  - Useful for geothermal exploration, site characterization, and reservoir assessment
- Funded as comprehensive Icelandic/USA cooperative project under the International Partnership for Geothermal Technology (IPGT) agreement
- Participations from US, Iceland and Sweden
  - ISOR and RU funding from GEORG Program (GEOthermal Research Group) & Swedish Science Foundation
- Project Progress and Plans:
  - Complete Baseline MT & MEQ imaging
  - FY13 & FY14 will focus on joint interpretation/imaging of combined data – Krysuvik and Hengill.

Project Management

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
5/15/2010	9/30/2014	5/15/2010	9/30/2014

Budget:

DOE Share: $3,205,226
Funding received in FY09: $0
Funding for FY10: $750,226
Funding for FY11: $175,000*
Funding for FY12: $830,000
Funding for FY13: $725,000
Requested funding for FY14: $725,000
Iceland/Sweden partners providing own funding & cost share

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
2/3	1/3	$3,031,554 (DOE)	$2,480,226 (DOE)	$3,306,968 (DOE+Cost Share)	$725,000 (DOE)