Why coring should be part of any exploratory high-temperature drilling project, as illustrated by the case histories of the Salton Sea Scientific Drilling Project (SSSDP) and the planned Iceland Deep Drilling Project (IDDP): a plea for technology development.

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The Purpose of this Presentation

- To illustrate the advantages of coring high-temperature geothermal wells
- Examples from the SSSDP
- History of planning for the IDDP
- Hybrid continuous coring system
- Spot coring
- Request for advice (& technology development)

The Salton Sea Geothermal System

375 MWe installed & 125 MWe under construction

SSSDP

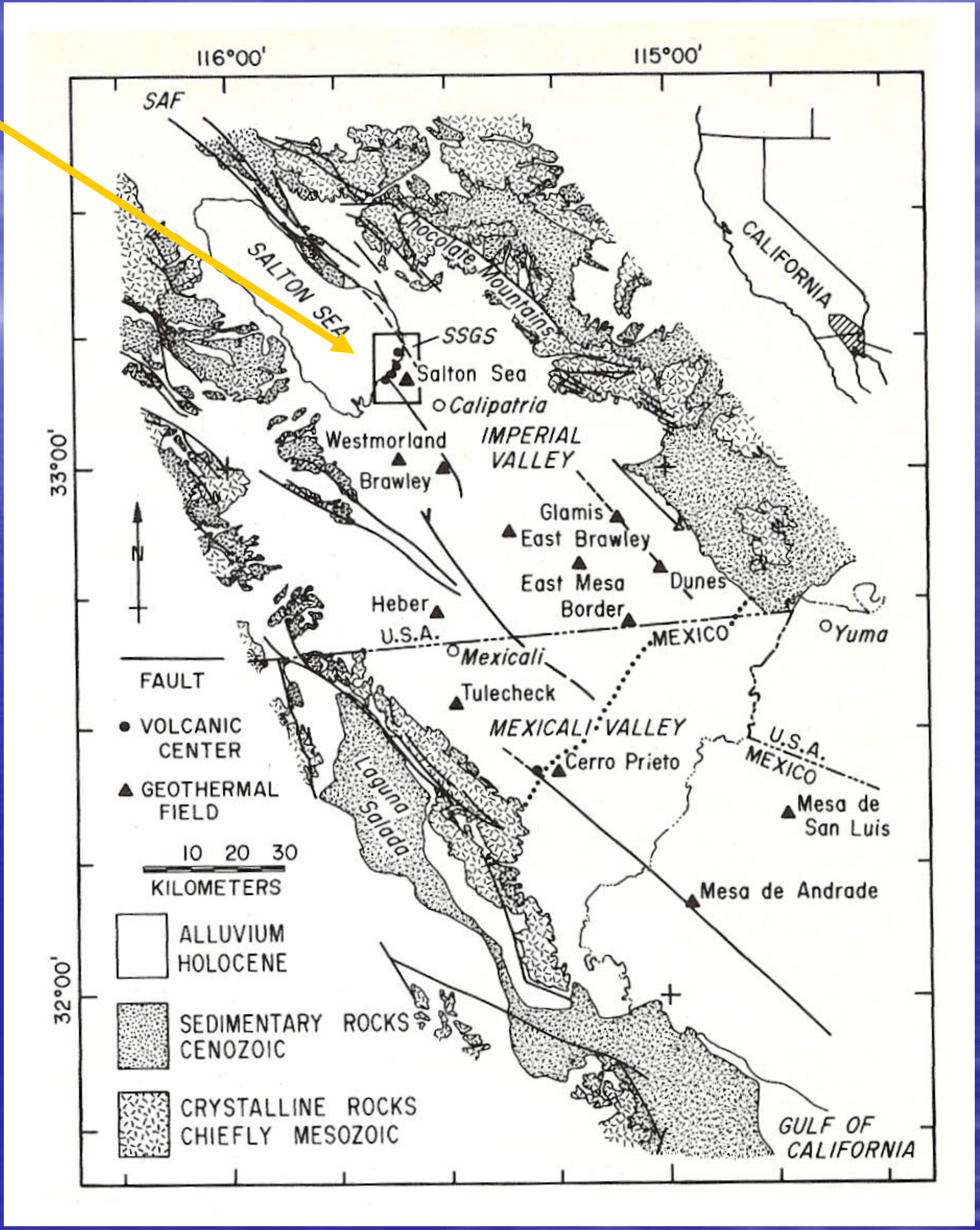
1985-86 drilled 3.22 km deep well

Bottomhole temperature >360 °C

Metal-rich brines ~ 25 wt% TDS

3 flow tests at different depths

224 m of cores recovered



SSSDP Fluids

Metal-rich brines
~ 25 wt% TDS

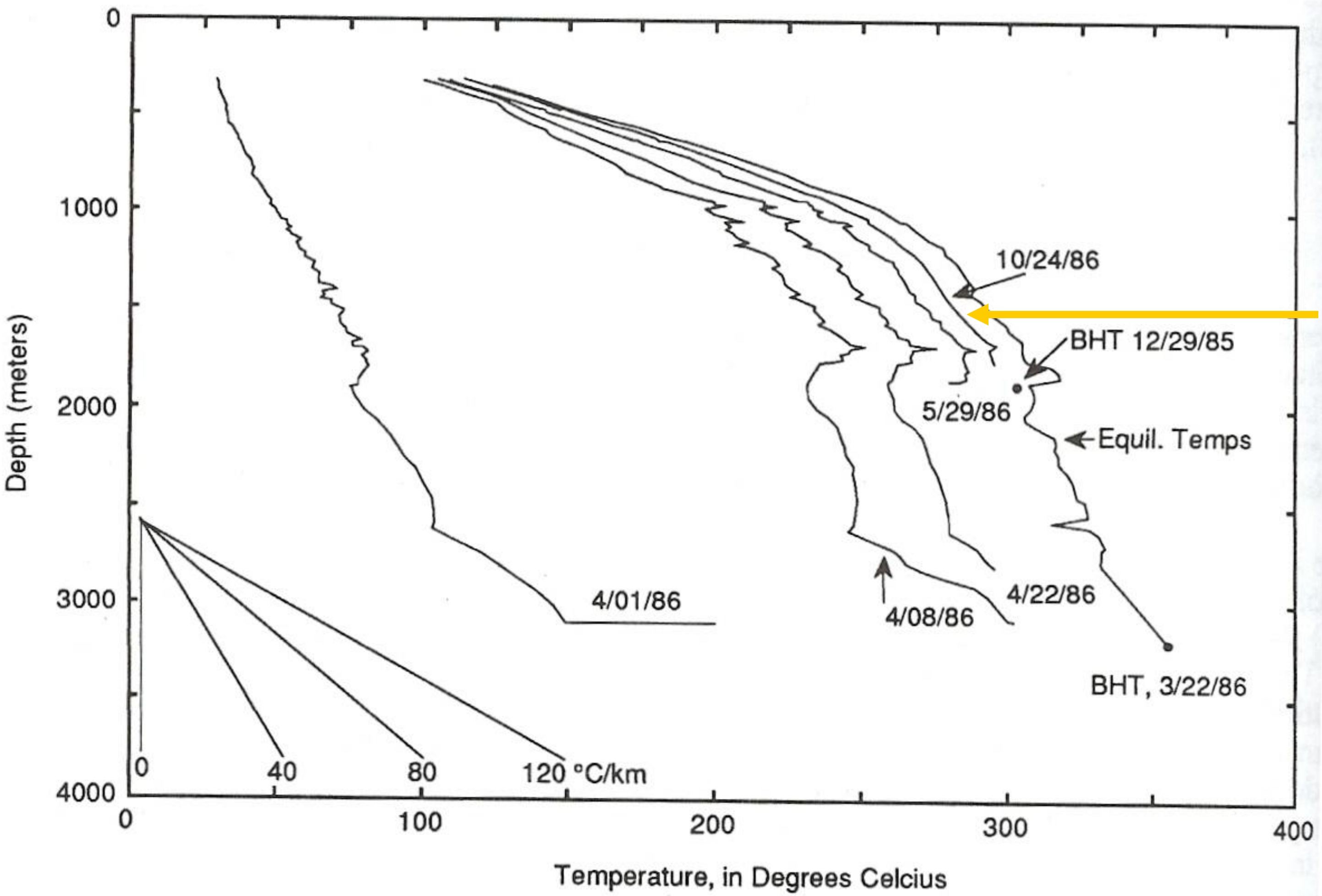
Flow rates > 370,000 kg/h at 1725 kPa

TABLE 3. Average Composition of Produced Fluids From State 2-14

Element	Parts Per Million (Weight) December, 1985*	Parts Per Million (Weight) March, 1986**
Na	52,661	52,200
Ca	26,515	27,100
K	16,502	16,900
Fe	1,522	1,630
Mn	1,385	1,430
Zn	506	483
Si	387	560
Sr	405	401
NH_4	336	314
B	253	258
Ba	194	336
Li	190	199
Pb	95	97
Mg	36	47
Cl	153,668	150,000
SO_4	110	50
TDS***	254,849	252,005
CO_2	1,664	1,500
H_2S	7	-

* First flow test analysis, adapted from Michels [1986b].
** Second flow test, A.E. Williams (unpublished data, 1986).
*** TDS, total dissolved solids.

SSSDP Temperature logs



Hung liner failed after 7 months

Figure 8.2 Temperature Log Summary; March-October 1986, State 2-14
(from Sass et al., JGR v.93, Bll, 1988, published by the American Geophysical Union).

Drilling and Coring Performance

Table 6. Drilling and Coring Performance Trends*

Depth Interval	Days to Complete	Average Cost/Day	Average Ft/Day	Average Cost/Ft	Delays
Surface to 3,500	21	$15,500	165	$ 95	One day setting conductor; one day fishing
3,500 to 6,000	23	$17,000	110	$155	Two days fishing; two days injectivity testing
6,000 to 7,000	20	$19,500	50	$390	Six days directional drilling; two days fishing
7,000 to 8,000	10	$19,500	100	$195	Two days directional drilling; two days lost circulation control
8,000 to 9,000	11	$26,000	90	$290	Five days lost circulation control
9,000 to 10,000	27	$24,500	35	$660	Damaged core bits; seven days lost circulation control and cementing; two days stuck pipe; two days well control
10,000 to 10,460	5	$23,000	90	$250	Two days well control; one day stuck pipe

* Excludes casing, flow tests, and logging activities.

Salton Sea Scientific Drilling Project
High Temperature Problems

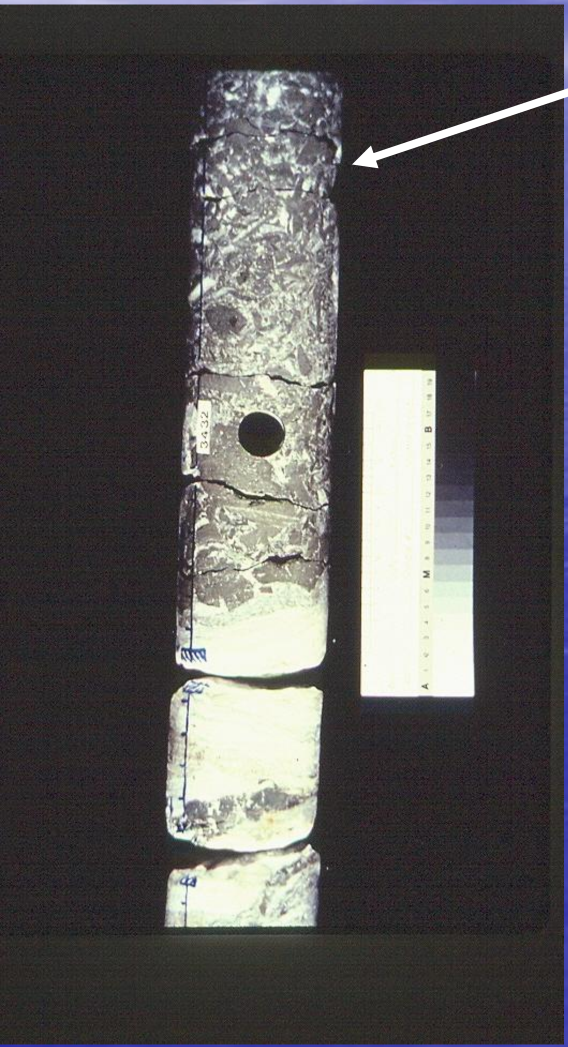
- Declining core recovery with increasing Temperatures.
- Loss circulation zones, well control and contamination
- Problems of isolating flow zones
- Low bit life while reaming
- Directional control at high temperatures
- Failure of downhole logging and sampling tools
- Failure of hung liner due to stress corrosion
- Fishing and stuck pipe

Planned to use USD 1 million to core 10% of well

(i.e. 320 m) - actually 224 m recovered

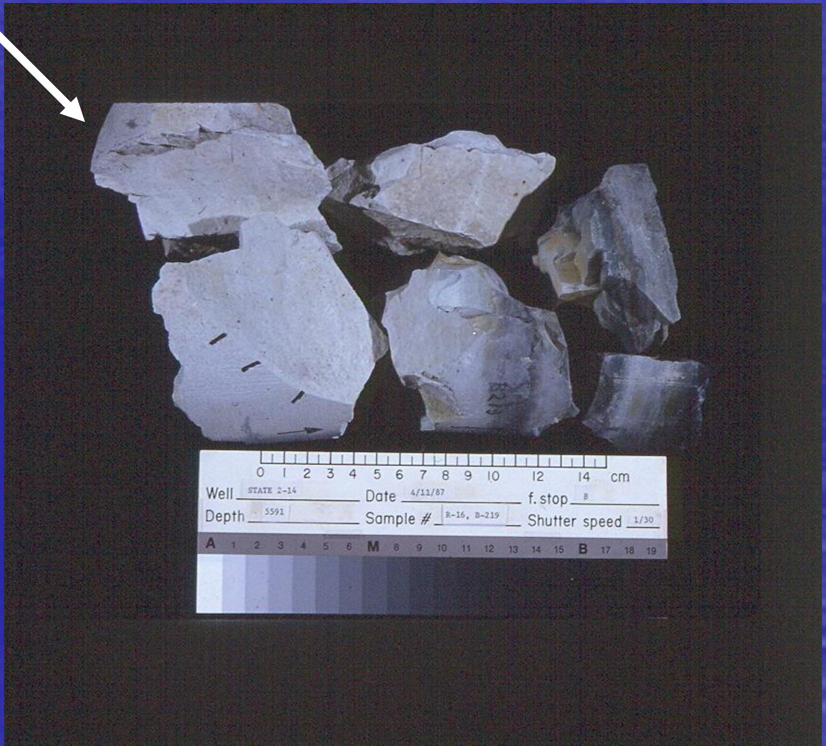
Planned to use 250 hours for logging – actually 487 hours needed

Some Cores a from SSSDP

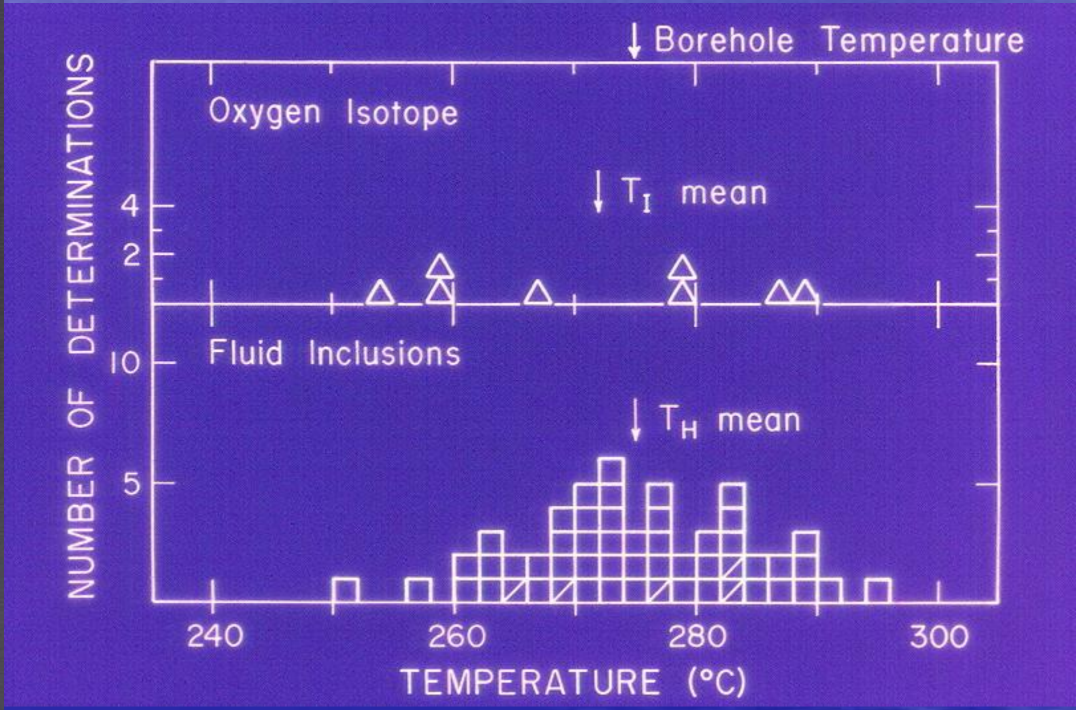


Anhydrite - cemented salt solution breccia from 1042 m. Source of salt is from dissolution of evaporite

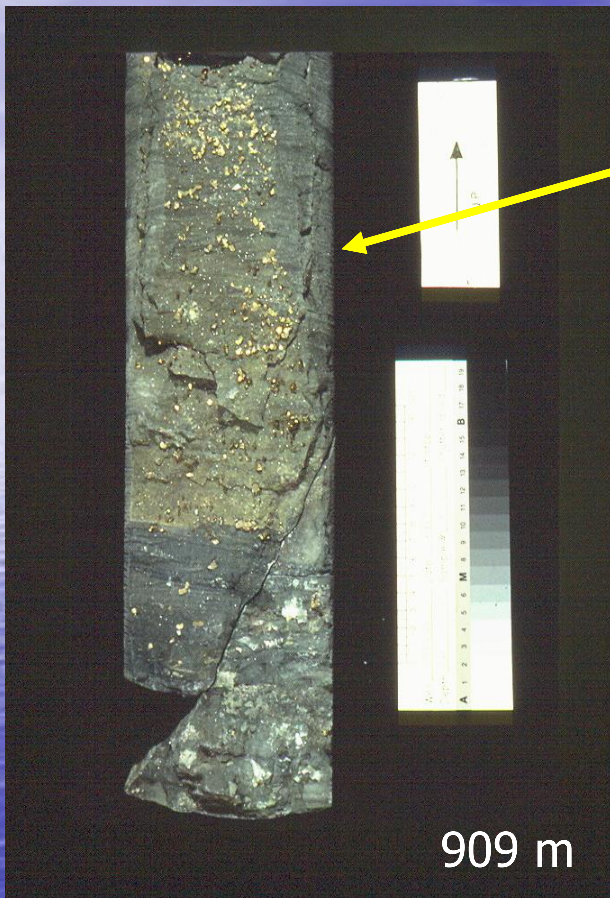
720,000 year old rhyolite tuff 1704 m, implies a subsidence rate of 2.4mm/year for 0.7 million years



Complex calcite vein 1240 m



Fractures and Vein Filling



TYPE 1 VEINS (EARLY)

COMPLETELY—FILLED

DOMINATED BY CARBONATE—SULFIDE ASSEMBLAGES

FORMED UNDER REDUCING CONDITIONS

FORMED UNDER A HIGH PALEO—THERMAL GRADIENT

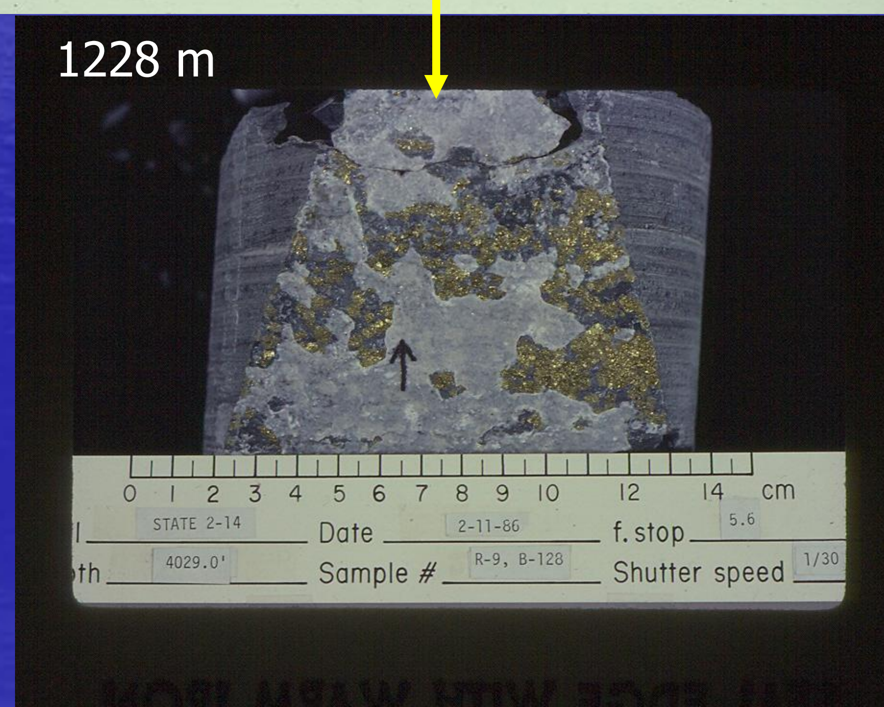
TYPE 2 VEINS (MODERN)

PARTIALLY—FILLED

DOMINATED BY SILICATE—SULFIDE—OXIDE ASSEMBLAGES

FORMED UNDER OXIDIZING CONDITIONS

FORMED UNDER MODERN THERMAL GRADIENT



Results of coring at Salton Sea

- Sedimentary and evaporitic facies analysis
- Source of salts
- Detailed petrography and isotopic analyses
- Structural relationships
- Igneous intrusive units
- Resolution of mineral paragenses
- Fracturing and vein-deposition sequences
- Petrophysical properties

Lessons learned from the SSSDP

- Flow testing of specific flow zones requires high-temperature packers or drill stem testing equipment
- Downhole logging and sampling equipment needs considerable development
- Cores are extremely useful -- but better coring systems are needed

Overall goal of the IDDP

Power output 50MWe from a single well?

Science Plan

- The IDDP well will produce fluid samples from a flow tests at ~ 4.0 to 4.5 km (and possibly 3.5 km)
- Drill cuttings down to 4.5 km depth
- Spot drill cores from 2.5 to 4.5 km depth
- Pressure, temperature and flow-meter logs over the whole drilled interval
- Depending on the fluid pressure, the drilled interval between 2.5 and 3.5 km should approach geochemical and pressure-temperature conditions similar to those of black smokers on oceanic spreading centres
- The second phase of drilling is designed to penetrate into supercritical fluids which must underlie black smoker hydrothermal systems, and which play an extremely important role in heat transfer and hydrothermal alteration
- Supercritical fluids have greatly enhanced rates of mass transfer and chemical reaction. These environments have never been available for such comprehensive direct study and sampling.

Issues at the IDDP that require coring

- Do natural supercritical fluids exist at drillable depths and do they have economic potential?
- What are the physical/chemical properties of natural supercritical fluid and of the rocks that contain them?
- How do supercritical fluids couple hydrothermal systems with magmatic heat sources?
- How do they affect chemical and mineral alteration, fracture propagation and fluid flow?
- What is the sequence of fracturing and vein filling in response to transitions from subcritical to supercritical conditions at the magma/hydrothermal interface?
- Cores are part of all major scientific drilling projects because they constitute a robust archival record as science progresses

Need for coring in IDDP Wells

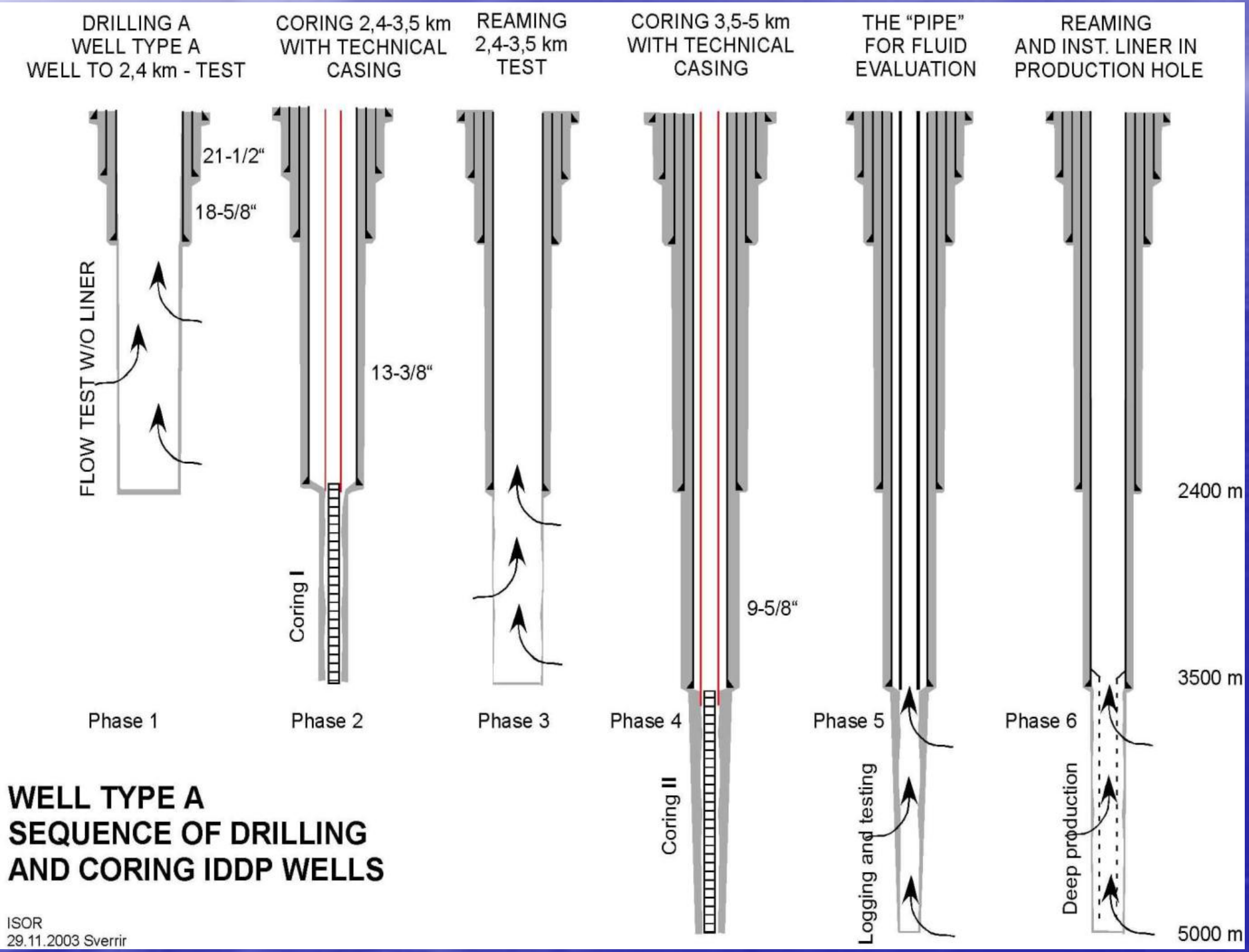
- How do we know when we are entering the critical PT-field?
  Reply: During drilling – only by combined mineralogy and on-site fluid inclusion studies

- What happens if we mix sub-critical with supercritical fluid?
  Reply: We wet the steam – and risk rapid acid corrosion of casing and scaling – and thereby we may lose the well – and may fail to prove the benefit of using supercritical fluid.

- Lost circulation yields no drill cuttings. In many wells in Iceland we experience total loss of circulation because of high permeability.

These are practical reasons enough to justify drill cores !

Sequence of drilling, casing, and testing originally proposed (2003)



0-2.4 km Rotary Drilling – Flow Test

2.4-3.5 km Continuous Coring –

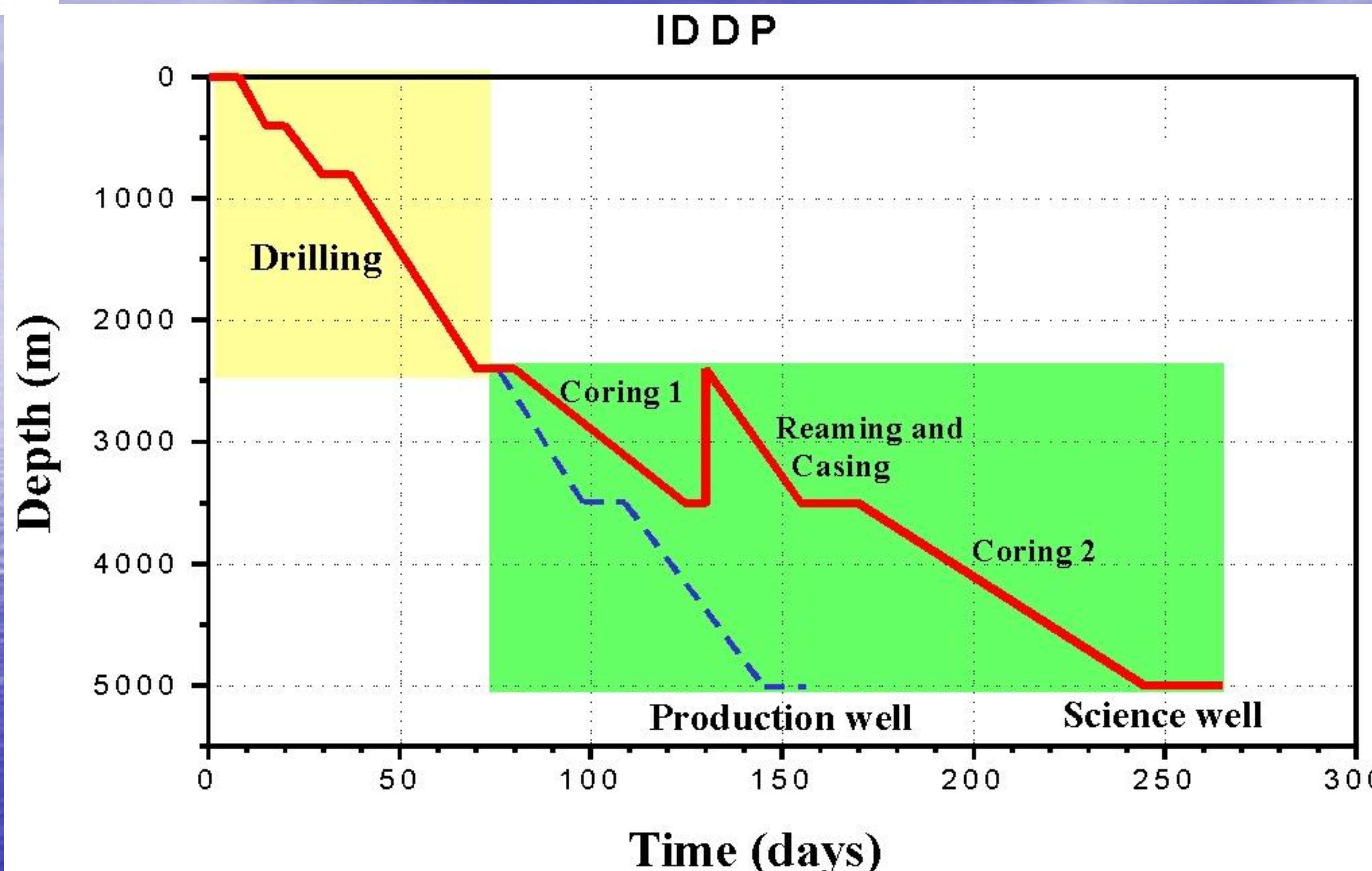
Reaming and Flow Test

3.5 -5.0 km

Continuous Coring and Flow Test

Reaming and Production Flow Test

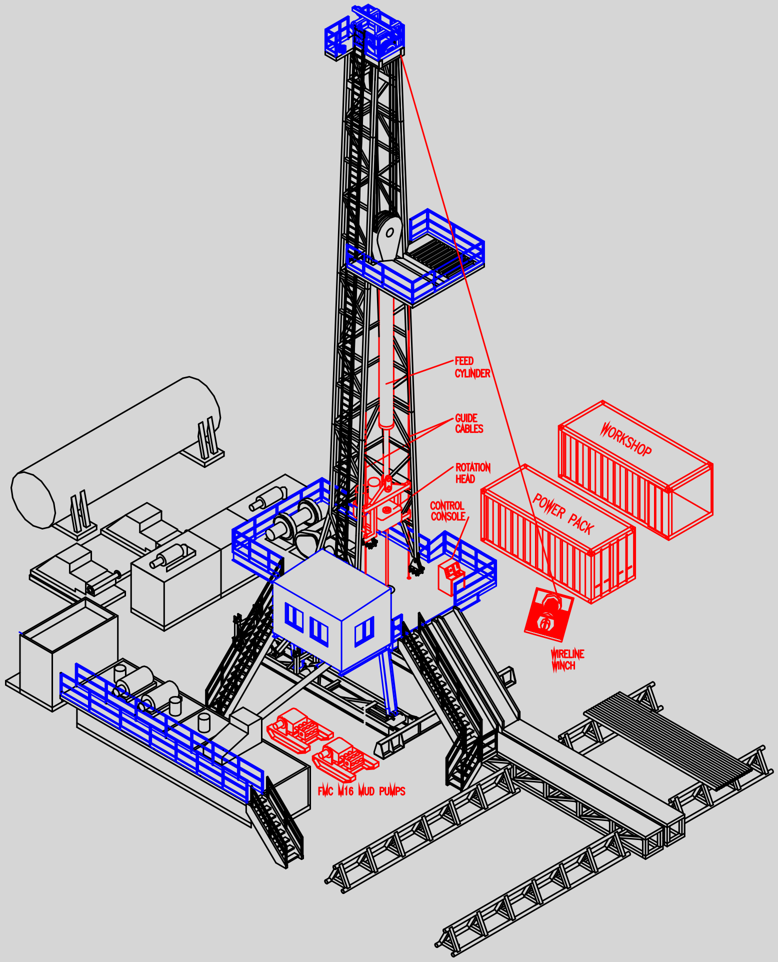
Plan proposed in 2003



Million USD	0	1	2	4	6	7	8	10	12	14	16

DOSECC Hybrid Coring System

Uses a mining type rig on the platform of a conventional rotary rig



DOSECC Hybrid Coring System

Combines positive features of rotary drilling and wireline coring

Conventional Rotary Rig

- Rotary Hole Drilling
- Tripping Drill Rods
- Setting Large and Multiple Casing Strings
- BOP Equipment

Wireline Diamond Core Drilling

- Continuous Wireline Coring for fewer trips
- Accurate bit weight and feed rate control
- Ability to core during complete lost circulation
- High Quality Core

Geothermal Wireline Coring

Initially Developed for UNOCAL's Indonesian Geothermal Projects

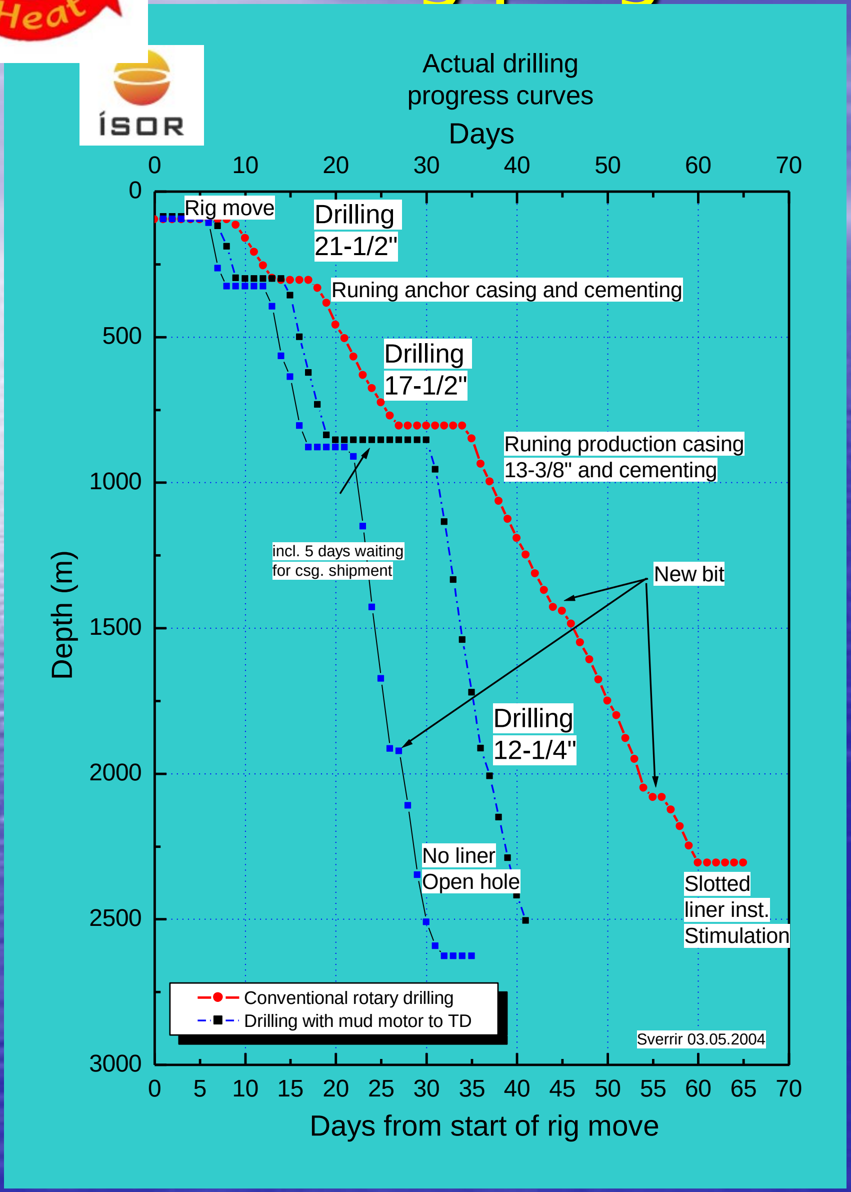
Location	Hole #	Depth (m)	T (°C)
Karaha	T-2	1383	321
Karaha	T-8	1327	288
Karaha	K-33	1992	256
Karaha	K-21	1654	259
Awibengkok	Awi 1-2	2439	232
Sumatra		2028	260
Hawaii	SOH-2	2973	348
New Mexico	VC-2b	1762	294

New & Old Drilling Rigs in Iceland

Hydraulic pipe handling, top drive

JOTUN - Rotary table

Drilling progress – days versus depth



Note: Improvements in recent years

ROP almost doubled by drilling with mud motors

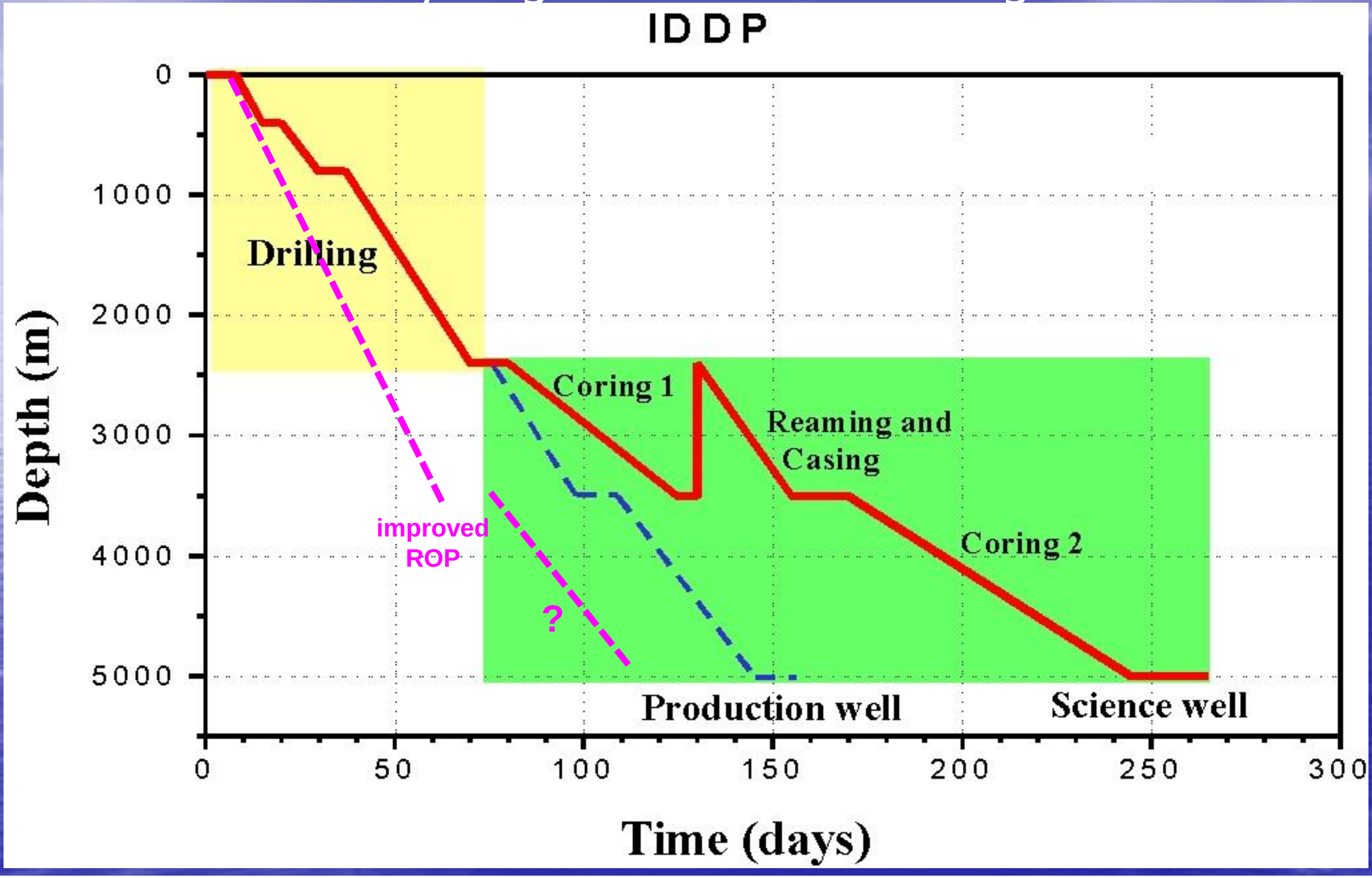
Trouble free drilling

Fewer bit changes

Aerated drilling added to improve well cleaning

(ROP ~ 200 m/day)

The Impact of these Innovations on Time Estimates is Offset by Huge Increases in Drilling Costs



Million USD 0 2 4 6 8 10 12 14 16 18 20 24 26 28 →

Decision not to use wireline coring

IDDP coring is clearly a NEW challenge for the DOSECC HCS system .The IDDP drilling engineers recommended rotary drilling and spot coring rather than continuous slimhole coring

Concerns:

Drillstring integrity (Drill Rods & BHA)

Cooling efficiency

In January and March 2007 we requested technical data from DOSECC on how to minimize these uncertainities, but received no new input.

Early in June, after further discussions with DOSECC, we relucantly decided to abandon continuous coring and settled for limited spot coring.

The InnovaRig is capable of both rotary and continuous wireline diamond drilling.

However it was not ready to bid on the IDDP drilling.

Also it has a very high mobilization costs.

InnovaRig

The new land drilling facility for scientific drilling

On May 14, 2007 a novel deep drilling and coring installation called "InnovaRig" was officially commissioned for its first operations test in the fabrication workshop in southern Germany. Up to 5 km (~ 16,000') deep drilling can be realized through the 52 m high derrick with a hook load of 3500 kN from summer 2007 on. The development of this drilling facility was triggered by the necessity for flexible, fast, and inexpensive drilling, sampling, as well as measuring in research projects. The facility is owned by the GFZ Potsdam but will be made available for both, scientific (e.g. ICDP) and industry projects through a commercial operator.

The main technical characteristics are that various drilling options including airlift drilling in large diameters, standard rotary drilling, continuous wireline diamond drilling, casing drilling as well as underbalanced drilling can be applied. The very high degree of automation assures low-cost operations, high working safety (hands-off technology), and a high degree of environmental protection including sophisticated noise protection and low-waste operations. The equipment is fully containerized for fast mobilisation and demobilisation,

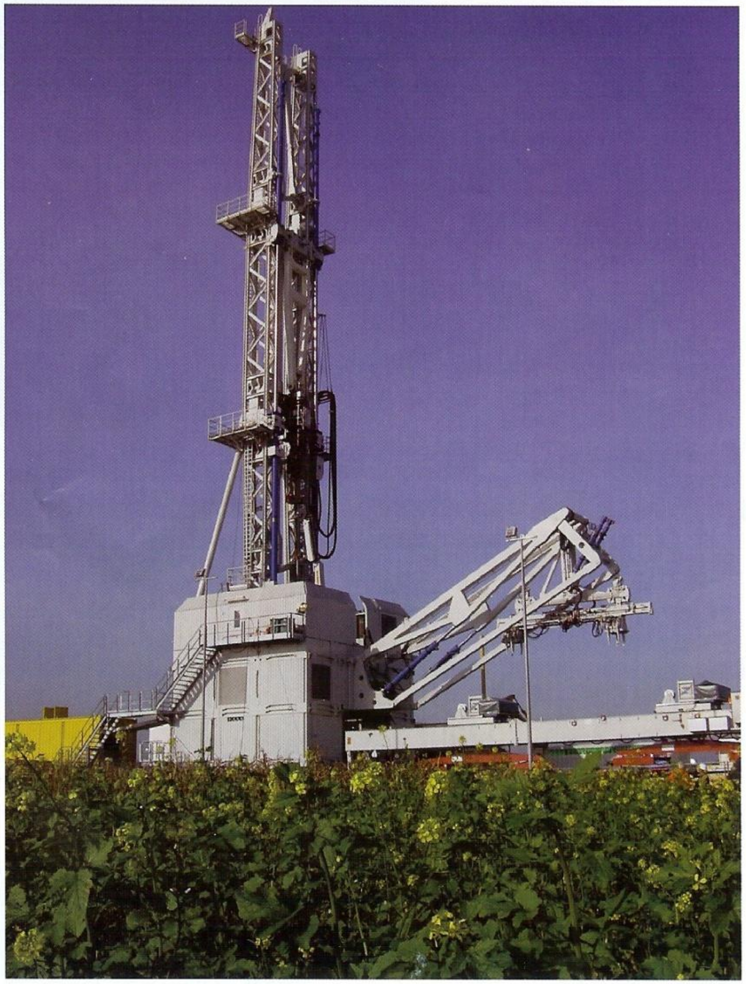
In the InnovaRig, the usual standard of a rope hoist carrying the drillstring or casings is replaced by a hydraulic double cylinder system with 2000 kW power and 22 m stroke. Drill pipe is handled with semi-automated connection of two pipes to one stand in horizontal position in a bridge magazine outside the derrick while a new type of pipe handler transports stands into the tower. All kinds of pipe and casing in sizes between 2⅞" to 24½" can be handled in the system, ensuring tripping speeds of up to 500 m/h. The pipe is driven through two separate top-drive systems with a broad range of rotary speeds. And furthermore, the mud system, tanks, and pumps are flexibly constructed for adaptation in the various drilling procedures.

In terms of energy consumption and environment protection, InnovaRig can be operated through internal and/or public power supply, can be operated with biogradable muds and grease, is fully noise shielded to allow deployments close to housing areas and will be extended for "waste-free" operations.

Backed by project demands in the ICDP and the increase in geothermal and CO_2-sequestration R&D projects, the Helmholtz Association of German Research Centres funded the development of this new drilling tool for Earth sciences through the GFZ Potsdam and an industry partner.

Ulrich Harms, ICDP

InnovaRig, May 2007. Photo courtesy of Ulrich Harms.



Current Status

- A balance needed to be struck between scientific rewards, costs, and safety.
- The first deep IDDP well should be rotary drilled to target depth (4.5 km) rather than continuously core drilled between 3.5-4.5 km.
- If total loss of circulation occurs during drilling, coring is the only way to get rock samples as drill cuttings will not be obtained. Accordingly, spot coring is recommended in the event of total circulation loss.

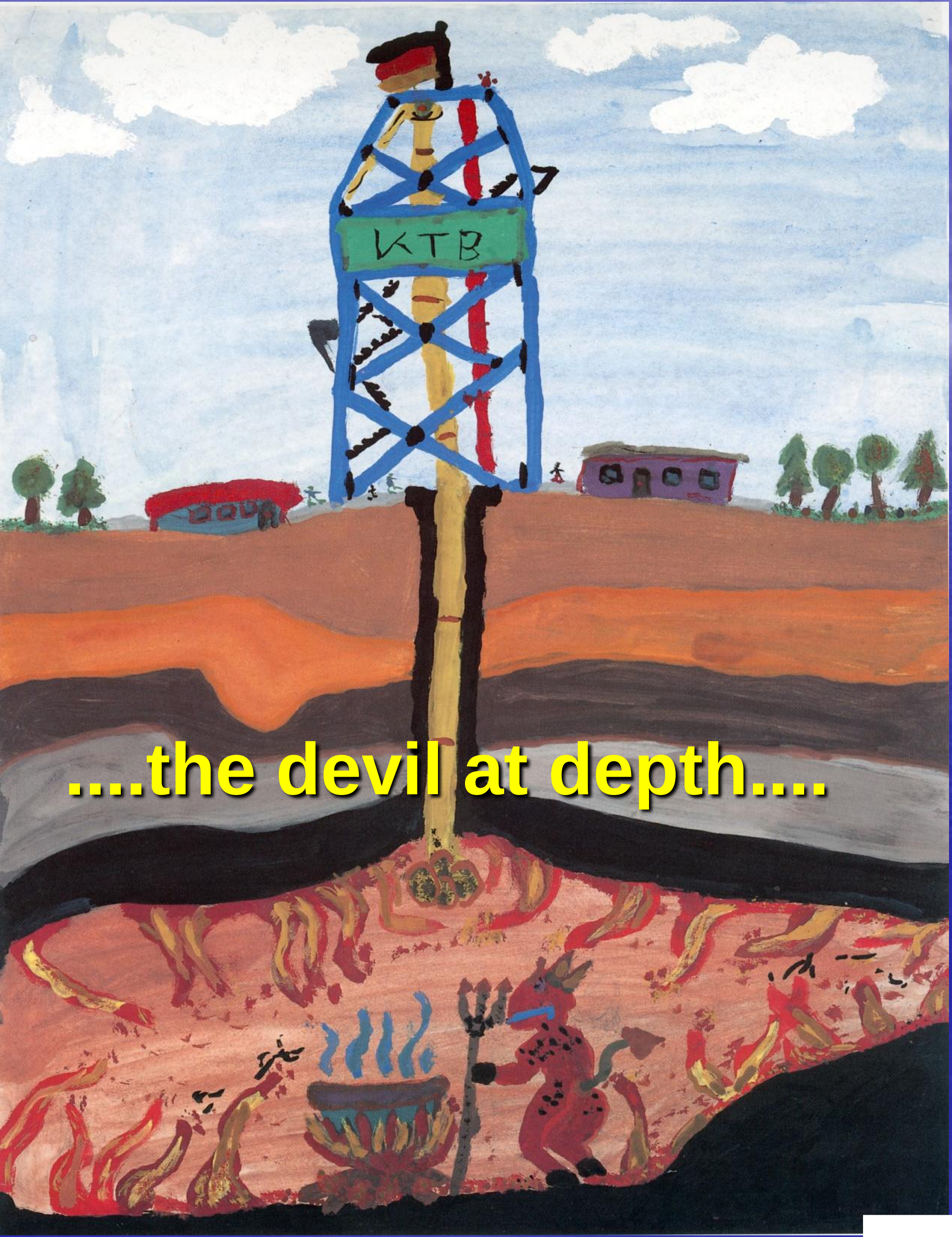
A Plea to the Engine Workshop

- The IDDP needs input on optimizing spot coring

(minimizing trips, avoiding jammed core barrels, core disking, etc.)

- Can we successfully spot core "blind", i.e. with total loss of circulation?
- How best can we control fluid pressures during coring?
- What about continuous coring in the IDDP in the future?

WE NEED TO IMPROVE CORING IN HIGH TEMPERATURE WELLS IN GENERAL



(From the KTB)

THANK YOU!

htpp://www.iddp.is