



BOREHOLE SURVEYING

The Art or
Science of
knowing where
we are...?

James Tweedie
GeoMEM Ltd.

Image courtesy of Imdex Ltd.

Why drill?

- ▶ To access resources
- ▶ To obtain information



Why Survey?

- To get borehole trajectory (path)
- Hence: Locate information in 3D

> Locational Borehole Surveys <



Section:

- ▶ A brief history (drilling and borehole surveying)
- ◆ Why survey boreholes?
- ◆ Current surveying methods / instruments
- ◆ Accuracy
- ◆ Testing
- ◆ Quality Control
- ◆ Summary and the future ?

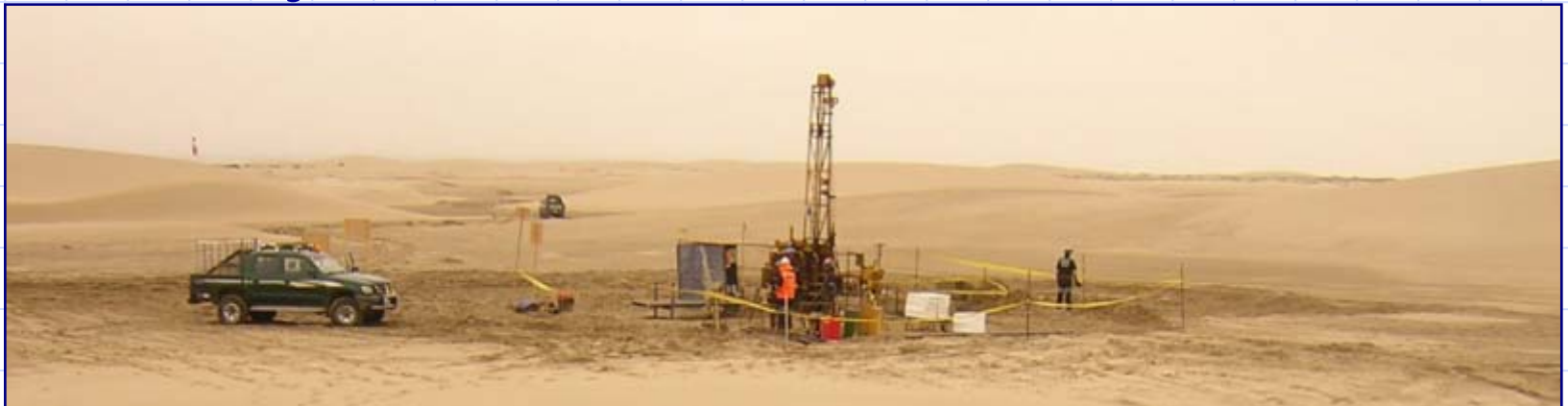
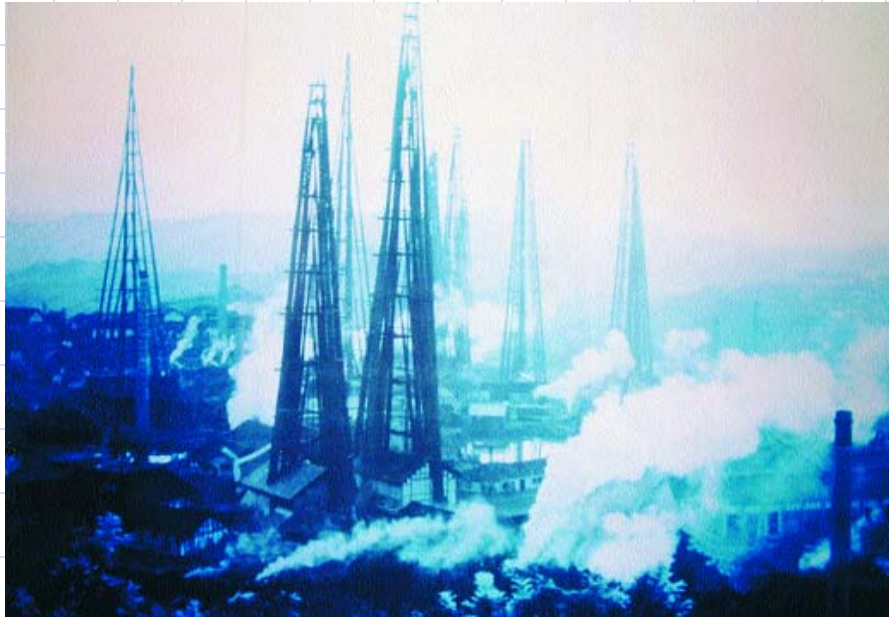


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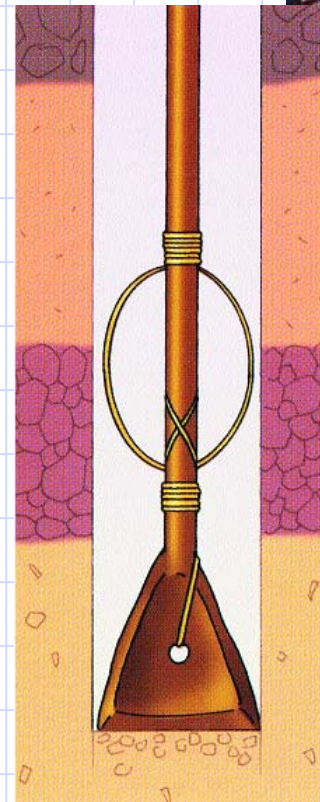
A brief history (China)

- 2000 years ago: First percussive drilling (bamboo rods)
- Circa 200 AD: Wells (for brine/salt) to 300m
- Circa 1050 AD: Flexible bamboo cable = greater drill depths
- 1700s: 300-400m wells are routine = industrial
- 1835: Shenghai well reaches 1000m = World first
- No record geological/geophysical investigation or surveying

Bamboo drills



A photo of Zigong in the early 1900s - derricks used to drill and produce brine and gas wells. Could be up to 100m high.



Model of the flexible bamboo "cable" rods.

"Fish tail" drill bit and bamboo rod

A brief history (contd.) “Western”

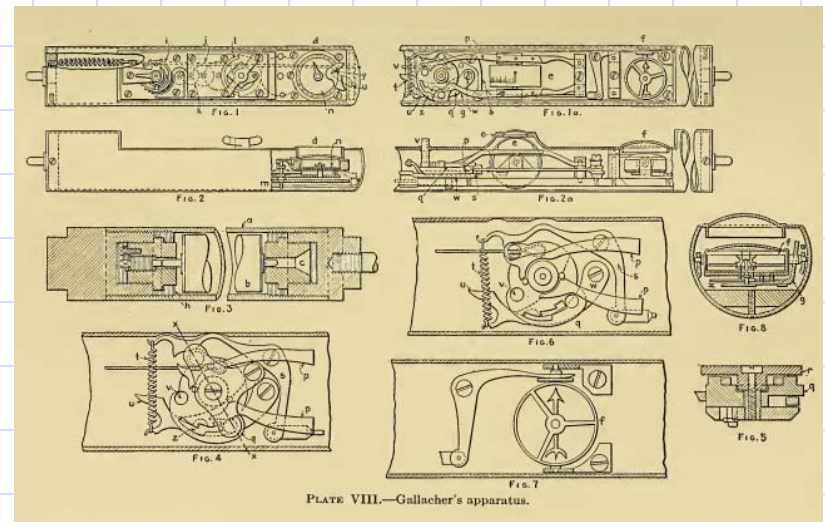
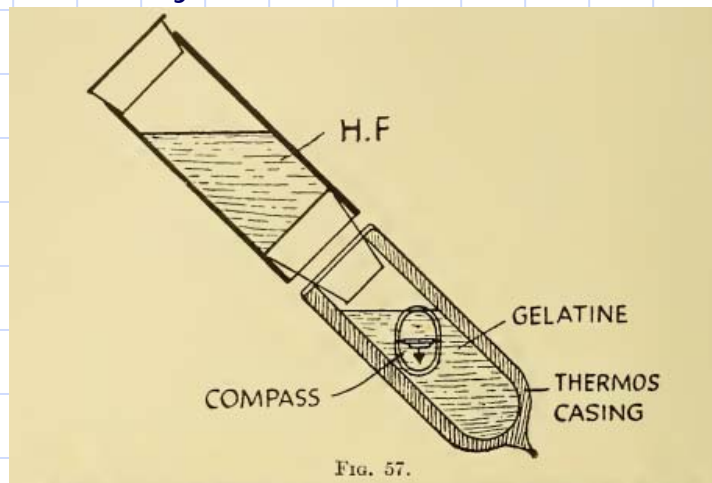
- 1800s: Percussive drilling / cable tool rig
- 1858/59: Drake: Steam driven cable tool rig, casing, oil!
- 1860s-1880s: Rotary drill developed/introduced
- 1870 onwards: Need to survey recognised, many attempts - Acid etch methods popular
- 1928: Alexander Anderson – research showed extensive deviation at end of holes
- 1925-1930: Sperry-Sun (Pew): SURWEL gyroscope
- 1940s – present: Rapid development of technologies

“Deep borehole surveys and problems”

M H Haddock (Mining & Technical Institute, Coalville, Leicester). (McGraw-Hill, 1931)

“That all deep boreholes deviate—and by deep boreholes we imply all those over 1,000 ft. in extent—is established beyond any doubt, and indeed much shallower boreholes deviate in more or less degree.”

Detailed book: borehole deviation; Surveying methods(10^{*})/devices; models & de-survey formulae.



* 10 methods: Fluid; Plummet & magnetic needle; Electrical; Pendulum; Photographic; Gyrostatic; Plastic cast; Pricker; Inertia and Seismographic.

Comments across the decades:

"The amount of trouble, litigation and random speculation that could be avoided by a correct knowledge of the course of deep boreholes is immeasurably great." M.H, Haddock 1931.

"Generally speaking the present geological engineer does not seem to be enamoured of the highly ingenious and exact suite of post-war instruments, being in many cases content to sacrifice precision to rapidity, ease and cheapness." M.H, Haddock 1931.

"The amount of drilling for exploration is vast, and this drilling is expensive. Notwithstanding this large investment, the quality of the information obtained from these drilling programmes is relatively poor." and " ... poor detailed knowledge of the orebody location..." Prof. Michael Hood, CTME, 1999.

"we are still accepting borehole surveys with inaccuracies of the order of 10% of the distance down hole." Anton Wolmarans (De Beers), 2005.

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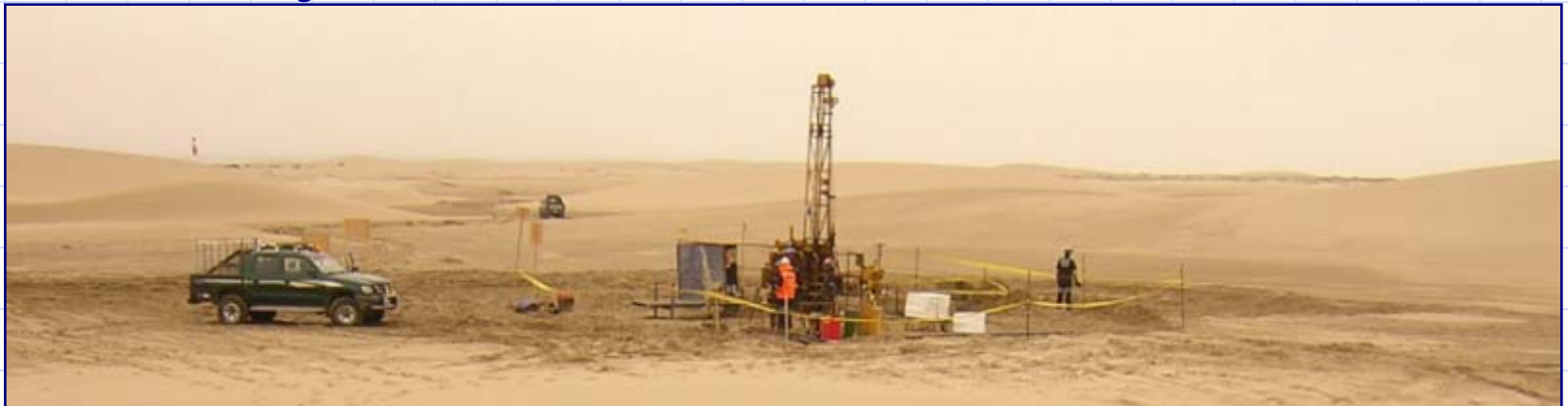


Photo courtesy of Dag Billger, Imdex Technology Sweden.

Why survey boreholes?

- Drilling is expensive
- Borehole data gathering is expensive
- All boreholes deviate

Therefore:

- Maximise value of data obtained
- Must know 3D location of that data

Why survey boreholes? (contd.)

“Downstream” operations rely on location of data:

- Directional drilling / orientation of wedges
- Planning hole extensions / branches
- Lithological logs and sections / 3D models
- Core orientation / structural analysis
- Geophysical data location
- Extraction planning (reserves, resources)
- Financial planning / Investment
- Engineering – tunnels, grouting
- Blasting – essential for explosive planning
- Geothermal holes / environmental monitoring

“Any non-trivial borehole that is not surveyed is incomplete”

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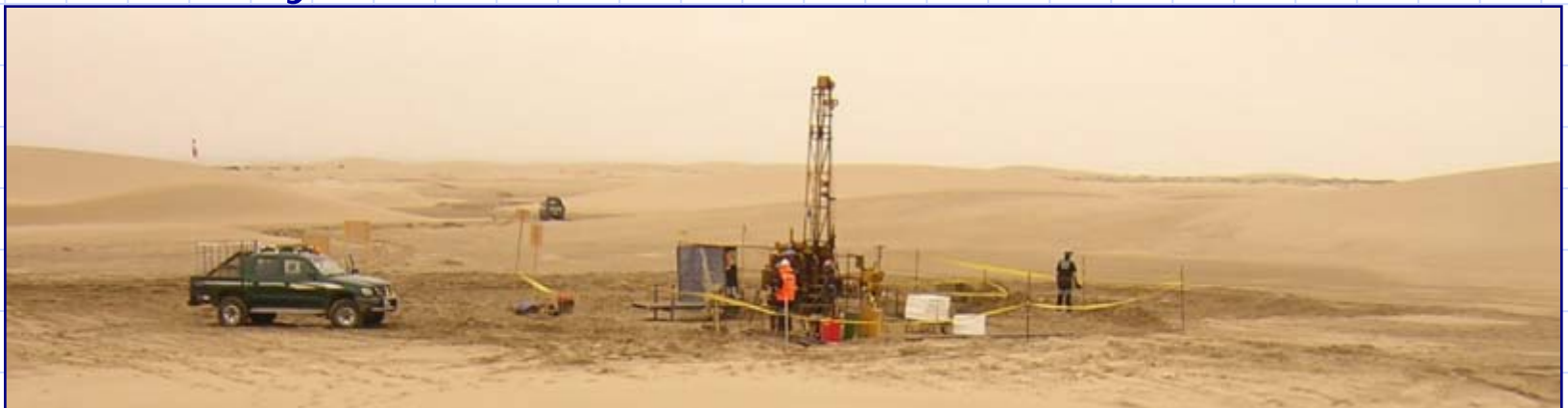


Photo courtesy of Dag Billger, Imdex Technology Sweden.

Current surveying methods / instruments

Main methods include:

- Electronic multishot (EMS) systems [magnetic]
- Gyroscope based (mechanical, laser, MEMS)
- Offset / optical (linked stations)
- Mechanical (e.g. Tropari / Pajari) [magnetic]

Almost all have data storage on board or transmit data to surface. Storage: Downloaded & processed when tool at surface.

Acid etch was still being used by one exploration company within the past decade.

Survey instruments

Available from a number of established companies.

- **Electronic** Multishot Systems (EMS) (accelerometer / magnetometer) now easy and low cost to manufacture
- **Gyroscope** systems are current development area: Miniaturisation of both mechanical / optical systems and development of MEMS gyros
- **Optical** instruments (linked survey) – still popular - low cost, non-magnetic.

Each industry or sector of industry has it's preferred survey methods – oil & gas usually leaders in development. But now innovative small diameter systems from mining / exploration.

Survey instruments

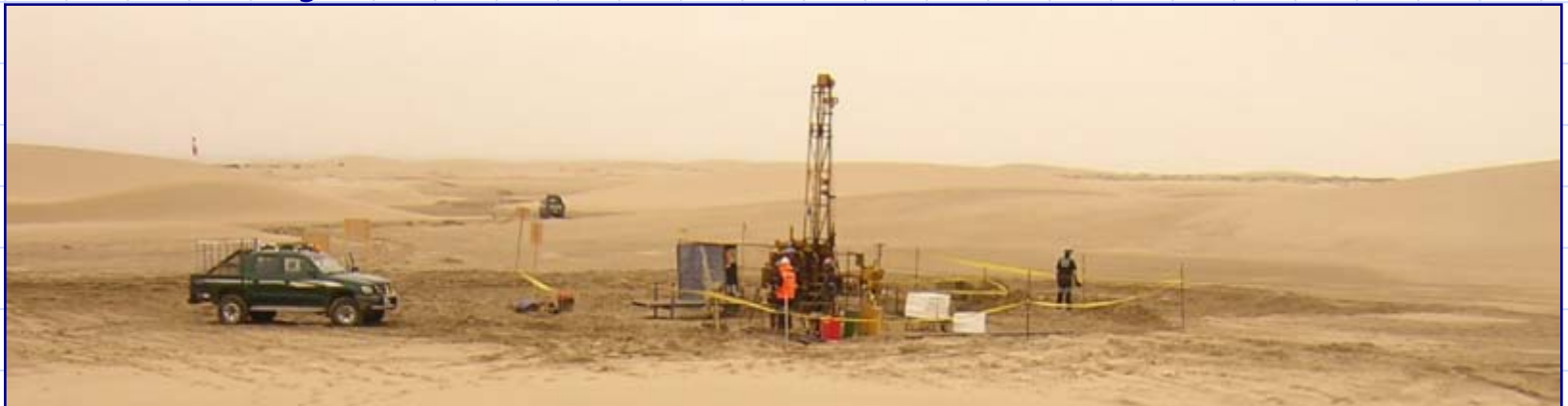


Test site for a MEMS Gyro instrument in petroleum exploration. Harrison County, Texas.

Transfer of technology from Mining to Oil & Gas industry !

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Accuracy:

“Any non-trivial borehole that is not *accurately* surveyed is incomplete”

Accuracy of survey depends on:

- Accuracy of instrument itself – (sensors, electronics, tolerances)
- Operational accuracy: during survey
- Calculation process
- Location on planet / environment

Accuracy:

Instrumental accuracy:

- Depends on sensitivity of sensors, electronic noise, magnetism (magnetometers). Drift in Gyro systems / compensation. Design!
- Usually quoted as result accuracy for the sensor:

Some published accuracy values from instrument manufacturers.

Tool type	Inclination	Direction	% hole length
Magnetic	+/-0.2	+/-1.0	ND
Non-magnetic	+/-0.01	+/-0.01	ND
Magnetic	+/-0.35	+/-0.35	ND
Non-magnetic	ND	ND	0.1%
Magnetic	+/-0.25	+/-0.35	ND
Non-magnetic	+/-0.2	+/-0.3	ND
Magnetic	+/-0.2	+/-0.3	ND
Magnetic	+/-0.1	+/-0.5	ND
Non-magnetic	+/-0.25	N/A	ND
Magnetic	+/-0.2	+/-1.0	ND

Accuracy:

Operational accuracy depends on several factors:

- Skill, knowledge & experience of operators
- Aspects of the borehole (open hole)
- Mechanical accuracy (centralisers)
- Environmental effects (temperature, magnetism)
- Spacing of measurements

Accuracy:

Calculation Accuracy:

Pre-processing: Usually initial calculations to obtain Direction / Inclination at measurement points.

Gyroscope (Navigation): Filtering (Kalman) processing for drift, temperature compensation, etc.

Final: De-surveying calculations (point to point):

- Tangential
- Average angle
- Minimum curvature
- Least squares

Accuracy:

Location / "Attitude":

- High latitudes: Steep magnetic field = loss of accuracy for Azimuth
- Horizontal surveys: Possible induced magnetic fields in steel rods

Accuracy:

So, Accuracy relies on three main areas:

- Accuracy of instrument, sensors, pre-processing controlled by manufacturer
- Accuracy of final de-surveying method used (software package)
- **Accuracy of operation controlled by surveyors**

How do we test accuracy of operation?

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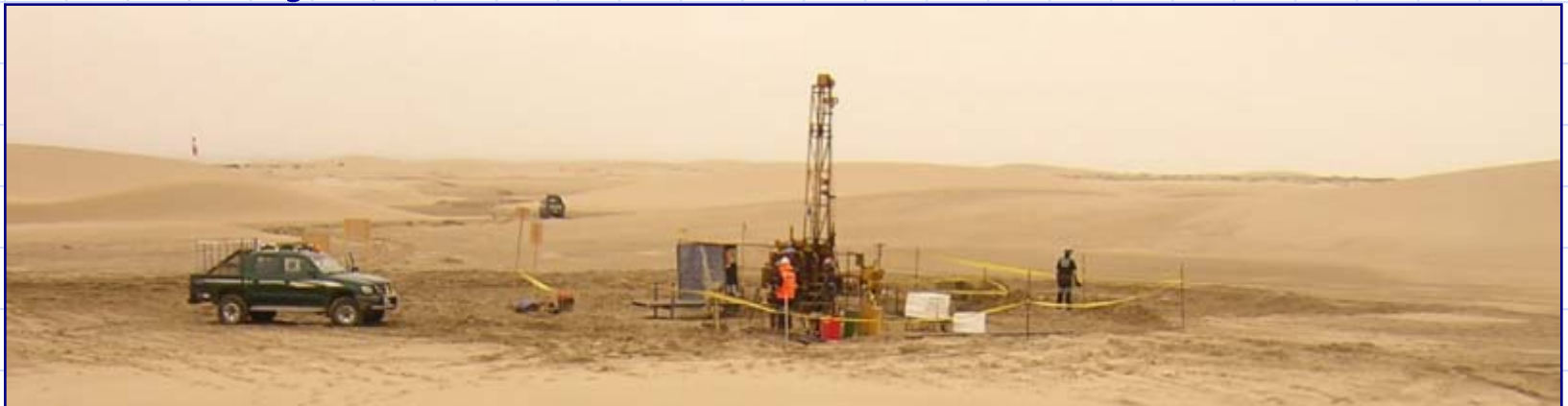


Photo courtesy of Dag Billger, Imdex Technology Sweden.

Testing:

Testing Survey Instruments (in test holes)

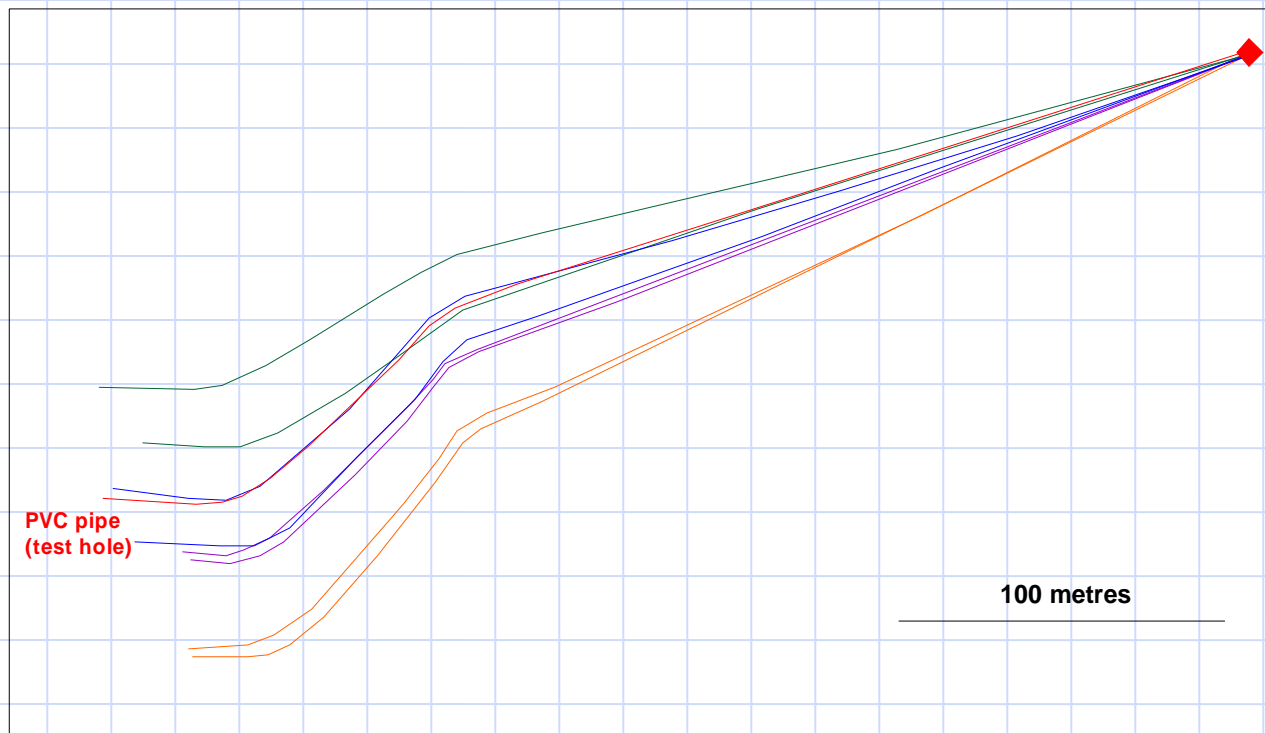
- Few or no standard test facilities
- Tests either at manufacturers or user sites
- Usually in-ground, and tests compared to other instruments.

Good / informative test by Anton Wolmarans (2005): Voorspoed (surface pipe) / De Beers.

Testing

Voorspoed test (2005) – approx 370m

Scatter of surveyed paths in plan around the Voorspoed test pipe. Largest scatter distance is approximately 75m. Colours show in and out runs of same instrument. Most show good precision (repeatability) without accuracy. Redrawn from Wolmarans (2005)



Accuracy varies from 0.1% to 14% of length for different instruments.

PLAN

Testing: Present status

- Tests in “Standard” boreholes are useful
- Best are “breakthrough” or surface (Voorspoed). Known end point.
- Most existing use known “good” instruments (gyro) as control (assumption of accuracy)?
- Most at instrument manufacturer, or larger user sites (cost)
- But no internationally recognised standard test sites for various industry sectors.

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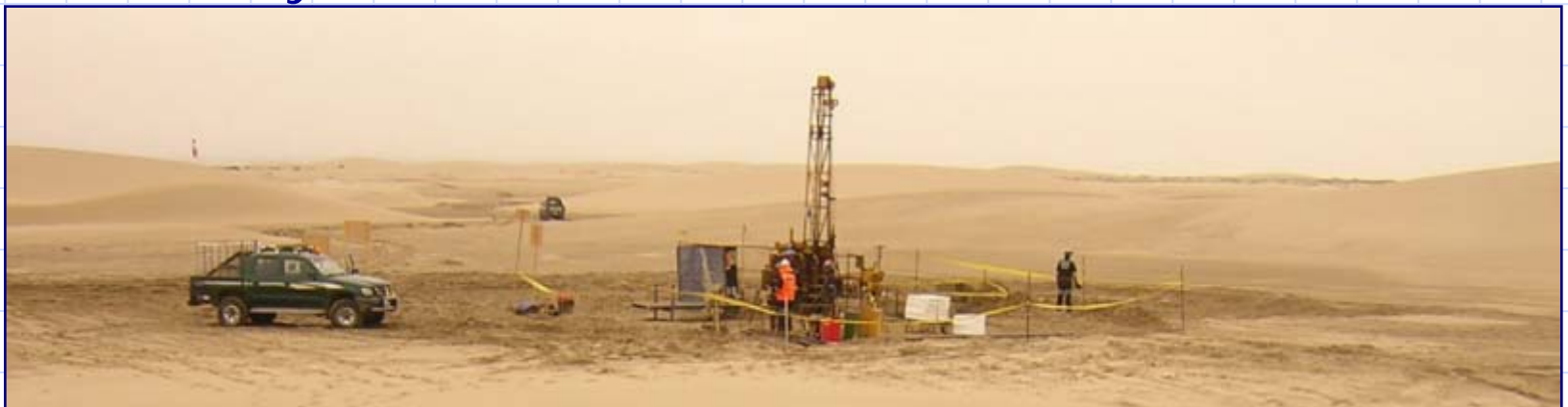


Photo courtesy of Dag Billger, Imdex Technology Sweden.

Quality Control: Typical survey data ...

Result Table

Results displayed for survey **PC532a**

On/Off buttons for table data blocks: **Angle** **Co-ord** **Offset** MagGrav Temp Tool Status Mag HV

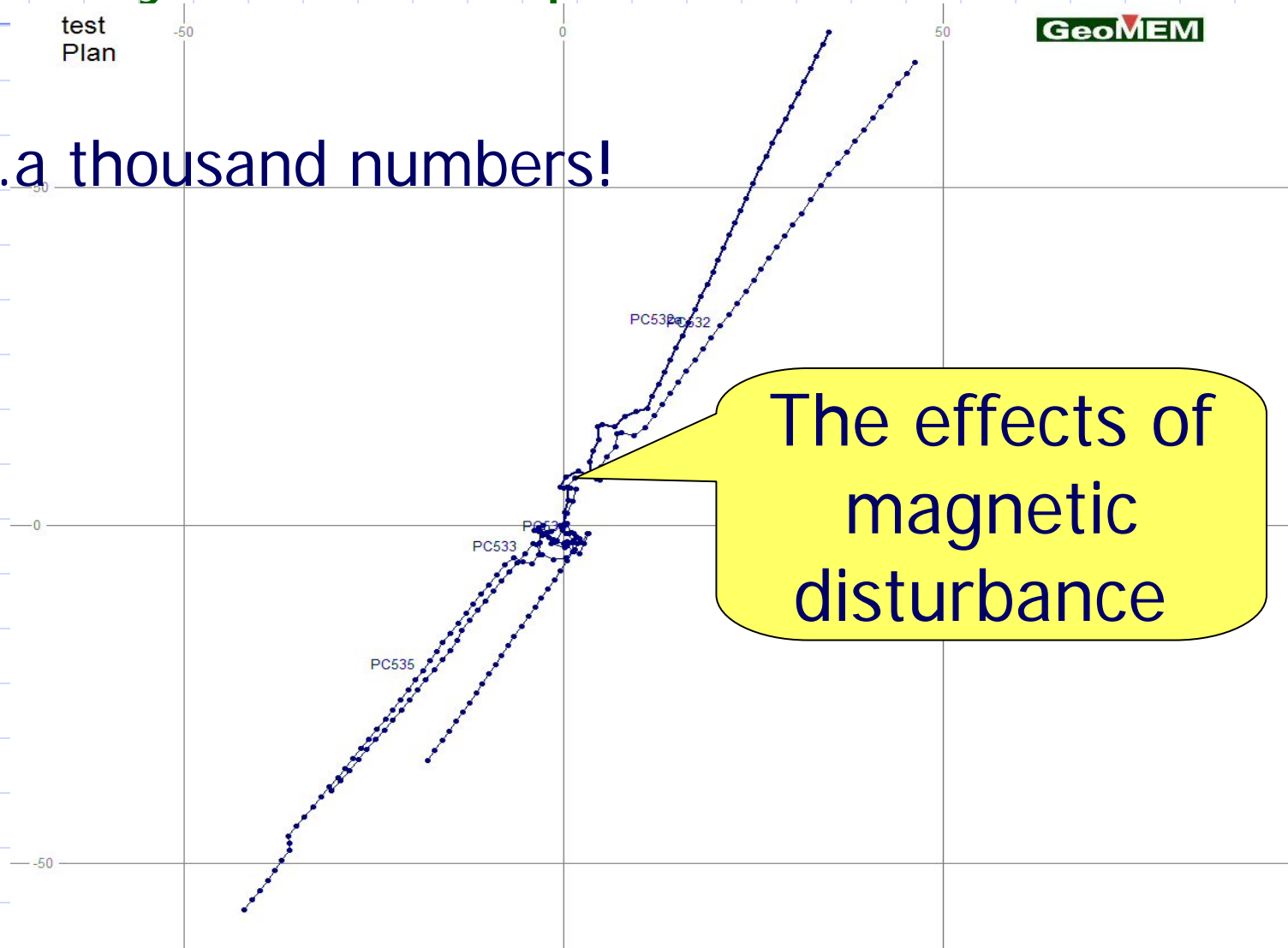
Command Menu:

- Export Data
- Distances
- Header Info
- Print
- Show Graphics
- Help
- Exit

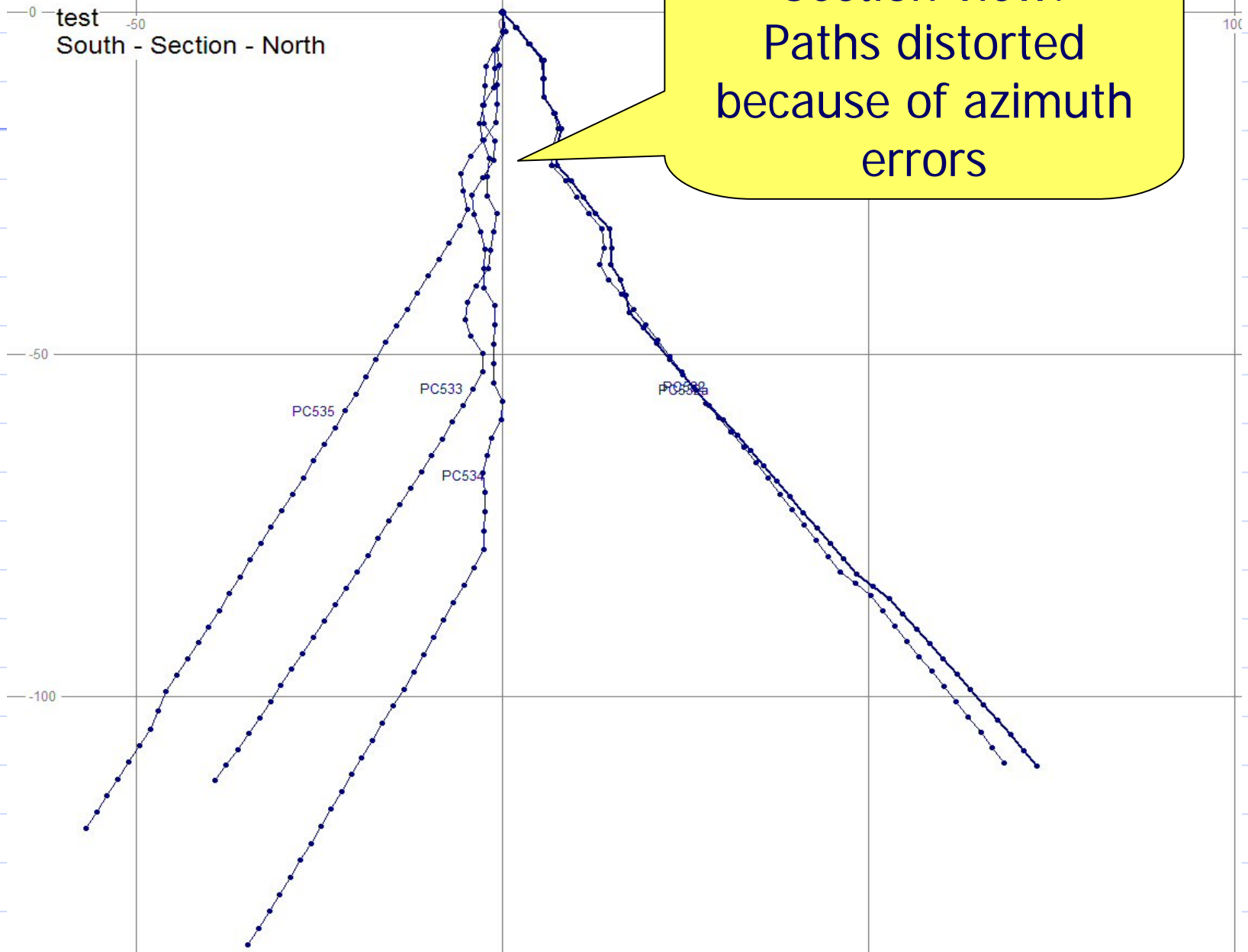
Station	Dip	Azimuth	Easting	Northing	Elevation	UpDown	LeftRight
Metres	Degrees	Degrees	Metres	Metres	Metres	Metres	Metres
11.0	-50.14	2.27	0.00	0.00	0.00	0.00	0.00
14.0	-50.04	9.12	0.19	1.91	-2.30	0.00	0.11
17.0	-49.91	18.99	0.66	3.78	-4.60	-0.03	0.51
20.0	-49.96	341.07	0.66	5.63	-6.93	-0.10	0.44
23.0	-50.08	196.50	-0.03	5.62	-9.63	-1.86	-0.25
26.0	-50.28	353.61	-0.48	5.66	-12.37	-3.61	-0.70
29.0	-49.68	59.63	0.28	7.16	-14.77	-3.96	0.00
32.0	-50.33	63.50	1.98	8.08	-17.07	-4.68	1.66
35.0	-50.23	167.98	3.15	7.52	-19.62	-6.71	2.85
38.0	-50.09	8.54	3.55	7.53	-22.36	-8.45	3.25
41.0	-49.84	344.73	3.44	9.43	-24.67	-8.48	3.06
44.0	-49.86	47.50	3.92	11.08	-27.06	-8.73	3.48
47.0	-49.76	2.40	4.69	12.74	-29.40	-8.93	4.18
50.0	-49.91	349.79	4.56	14.66	-31.70	-8.93	3.97
53.0	-49.35	134.97	5.17	14.97	-34.40	-10.41	4.57
56.0	-49.95	61.91	6.80	14.72	-36.81	-12.10	6.21
59.0	-42.89	24.26	8.13	16.20	-39.02	-12.33	7.48
62.0	-48.18	114.04	9.63	16.85	-41.37	-13.29	8.95
65.0	-49.46	21.45	11.01	17.40	-43.83	-14.41	10.32
68.0	-49.42	22.88	11.75	19.21	-46.11	-14.47	10.98
71.0	-49.42	23.00	12.51	21.00	-48.39	-14.52	11.67

Quality Control: A picture is worth

...a thousand numbers!



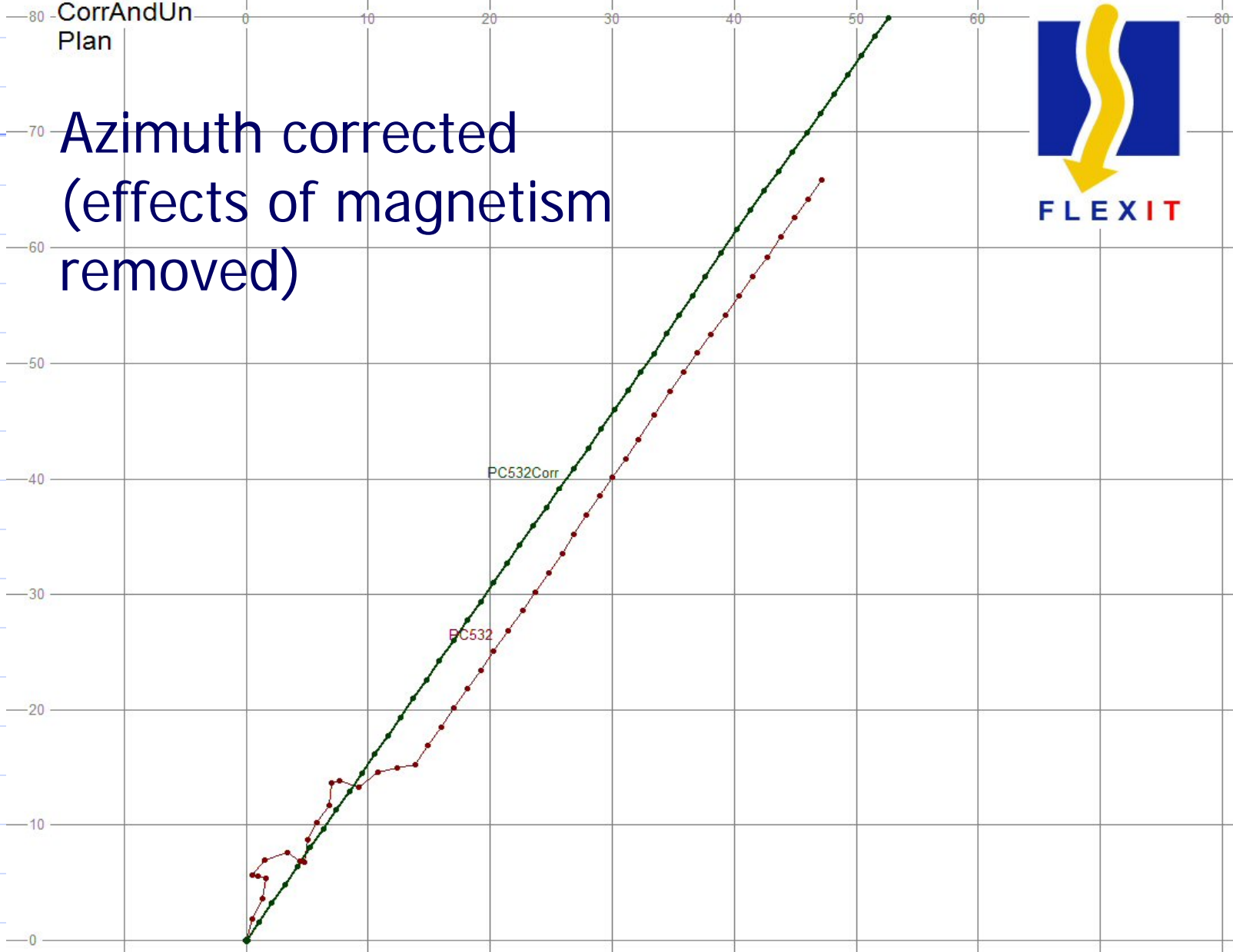
test
South - Section - North



Section view:
Paths distorted
because of azimuth
errors

CorrAndUn
Plan

Azimuth corrected
(effects of magnetism
removed)



Quality Control: Inclination data

Accelerometers / Inclinometers (Inclination / Dip)

- In a wide range of Instruments: primary or supplementary (e.g. in Gyro)
- Present generation are pretty accurate – improving all the time.

However: If moving or vibrating then incorrect readings. Easy to spot (high/low gravity).

Again: An operationally induced error.

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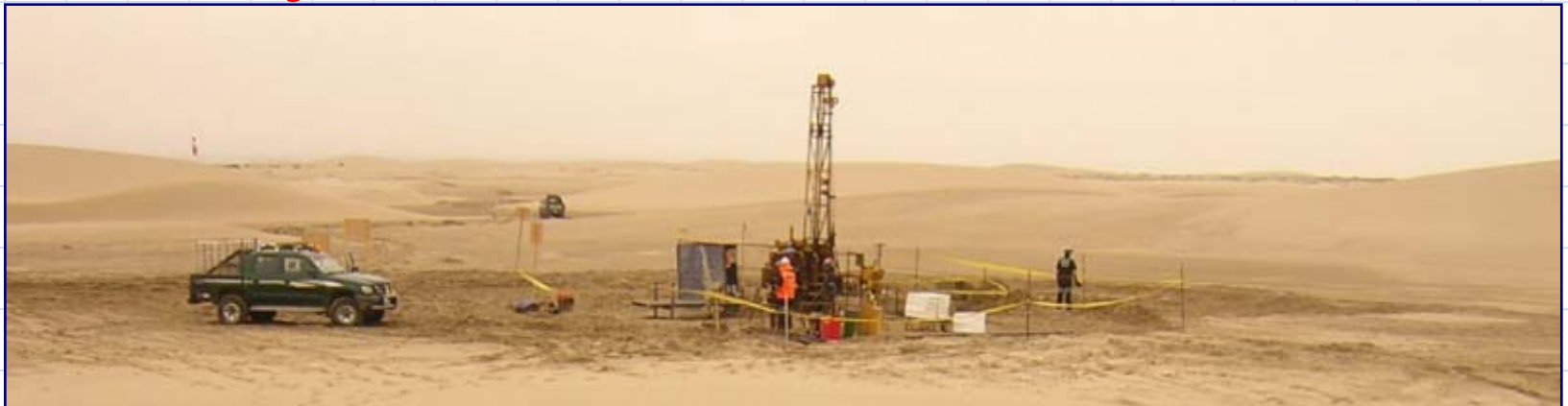


Photo courtesy of Dag Billger, Imdex Technology Sweden.

Summary: Sources of inaccuracy

- Noise and tolerance of electronics/sensors.
- Pre-processing/filtering processes
- De-surveying calculations

But mainly:

- **Survey operation and location / environment**

Summary: Survey operators

Therefore operators should be:

- Knowledgeable about the survey system(s)
- Recognise system strengths & limitations
- Skilled in operation of instrument

That is: Fully trained, experienced.

The future ?

- Survey instruments becoming smaller and more powerful
- Gyro systems with EMS sensors. Dual / multi-purpose systems?
- High speed data links for MWD/Directional drilling?
- Professional qualifications for borehole surveyors?
- Professional status / recognition for borehole surveyors?
- International standard borehole survey instrument test sites (for each industry sector)?

GeoMEM

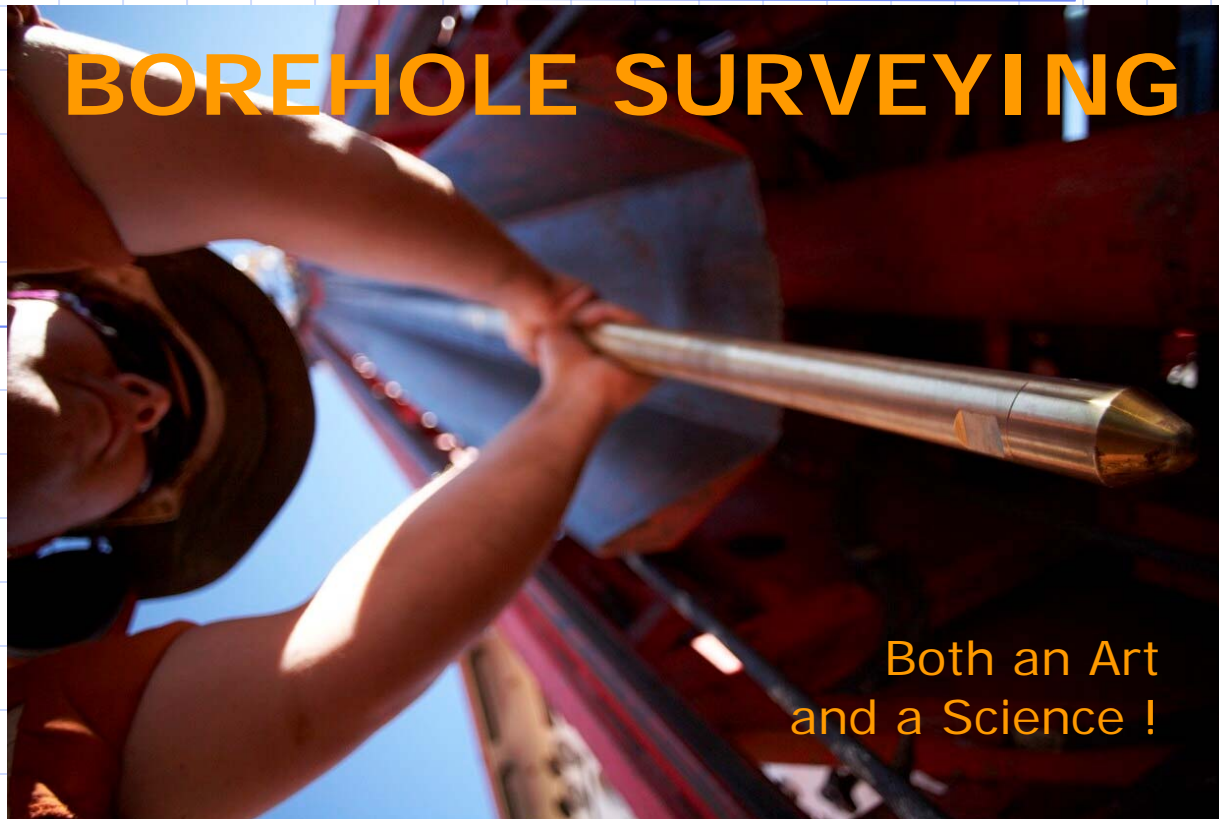


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