- Precision of a well header location. Contributing factors from seismic data
- Martin W. Rayson

Speaker Information

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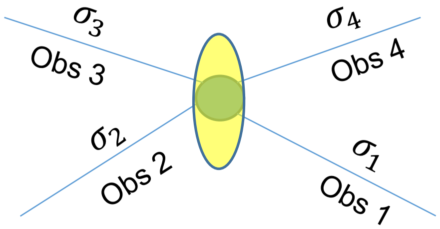
- Precision of a well header location. Contributing factors from seismic data.
- April 11th 2018
- Geomatic Solutions

Speaker Bio

- Introduction
  - Geomatic Solutions – Principal geodesist
  - 25+ yrs, seismic exploration and geomatics
  - M.Sc. Geophysics, Ph.D. Survey sciences
  - Kuala Lumpur, Malaysia; Newcastle, UK
  - Specializing in:
    - Seismic acquisition – positioning and navigation QA/QC
    - Interpretation station positioning audits

Introduction – error propagation



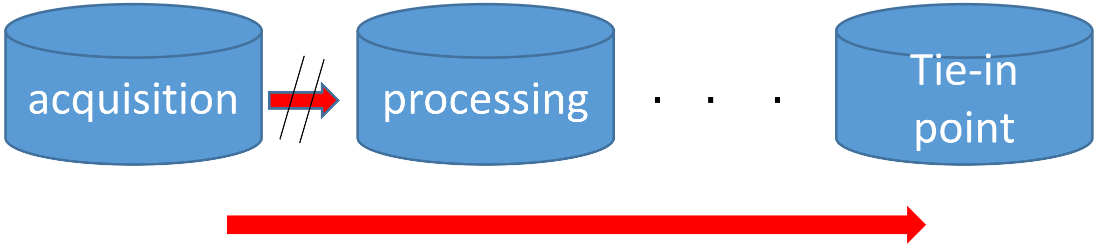
Observation error is unavoidable, regardless of survey activity, e.g. seismic positioning, well bore

A position is worthless unless accompanied by some form of quality measure, e.g. precision

Creation of a unified model with errors contributing from all data silos.

Are the precision measures contained in the seismic trace data propagated correctly?

<u>Data silos</u>

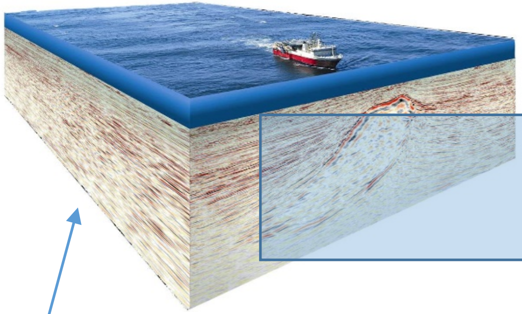


Error propagation, if permitted

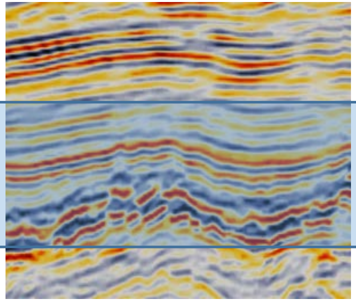
Is precision of the tie-in point adequately described from errors from other silos?

Siloed survey activities – error propagation…..

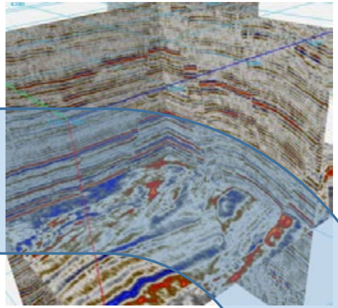
Seismic acquisition



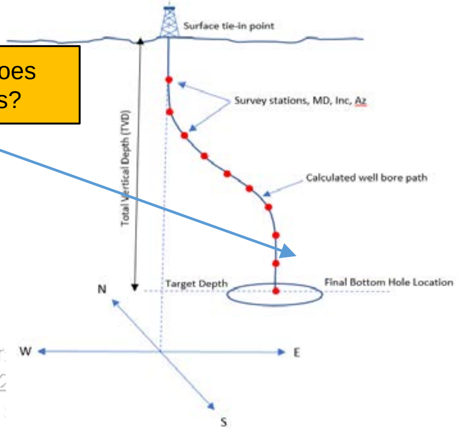
Seismic processing



Data loading



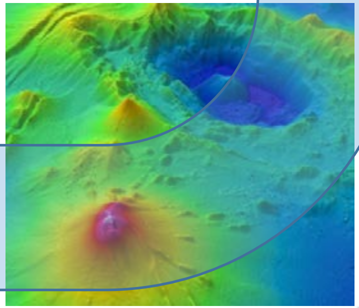
Well bore survey



What bearing does this have on this?

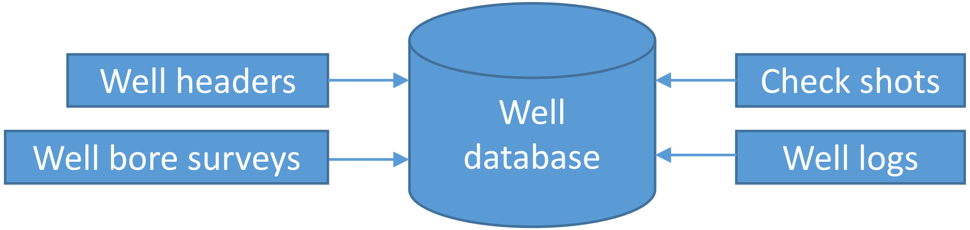
Rig move

Geo-hazard surveys



What started this study?

Creation of new replacement database comprising 12000+ wells within a controlled Data Quality Metrics (DQM) environment.



Well headers: Assignment of coordinate tuples, CRS', *accuracy statement* (*with probability*) and commentary.

From where? Audit trail conducted on horizontal surface positions, from description of the seismic survey bin grids, processing grids and data loading to interpretation workstation. Conducted by Geomatics Dept., Seismic Acquisition and Seismic Processing.

Logic: If there are errors in the seismic trace data there will be errors of at least the same magnitude within surface activity performed afterwards, including well header positions.

Well header load sheets and captured metadata

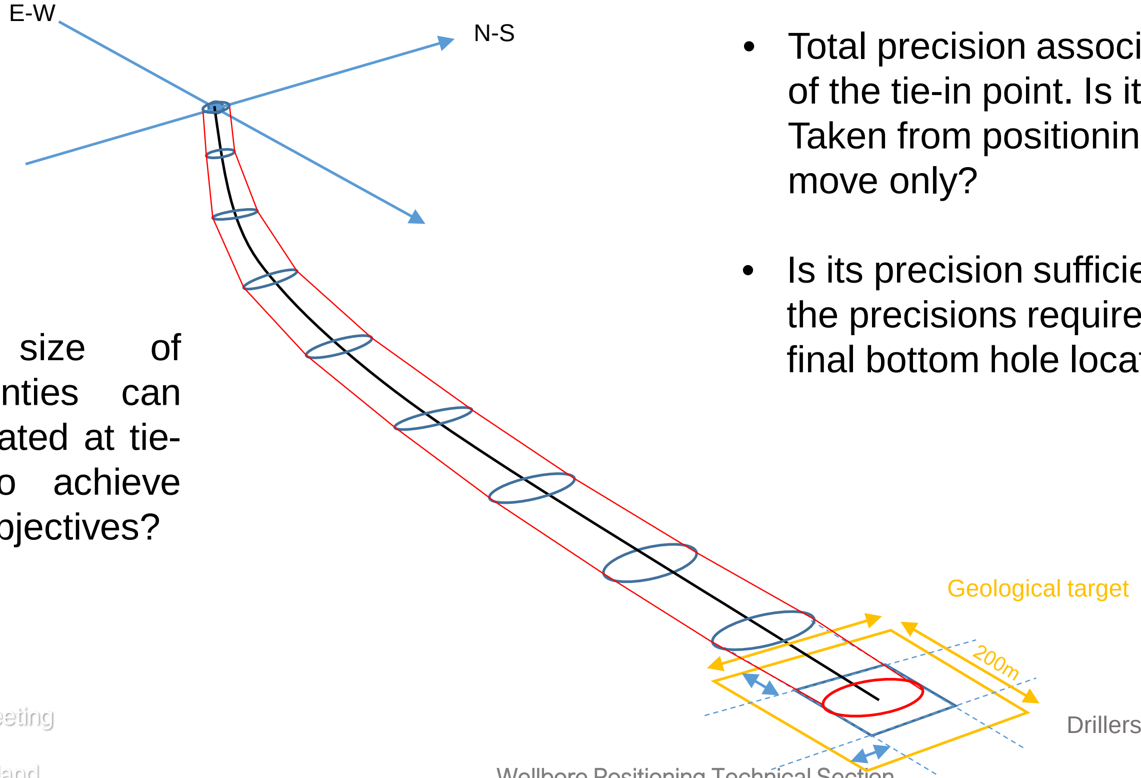
- All metadata were captured within the new wells database, along with other notable parameters:

- Rig type
- Rig elevation
- Spud date
- Magnetic Dec. model
- Magnetic Dec. value
- Grid convergence model
- Grid convergence value
- Water depth
- Well environment ………..

WELL NAME: MWR-1			
Country:	Malaysia	Block:	Open
Projected 2D CRS:	WGS 84 / UTM zone 49N	Easting: 760866.20	
EPGS Code:	32649	Northing: 486742.59	
Geographic 2D CRS:	WGS 84	Latitude: 04° 23' 59.6778" N	
EPSG Code	4326	Longitude: 113° 21' 02.0361" E	
Radial accuracy:	400 m	Probability:	95%
Additional comments:	All seismic acquisition and seismic processing reports are available, as too are the load sheets used by data loaders. However, acquisition report states CRS as being WGS 84 / UTM zone 49N, whereas the seismic processing report states CRS as being Timbalai 1948 / UTM zone 49N. No details of a coordinate transformation being applied can be found.		

Coordinate Set 1 Base geographic CRS: WGS 84		Coordinate Operation	Coordinate Set 2 Base geographic CRS: Timbalai 1948	
CRS name: Tuple 1	WGS 84	Type: Transformation EPSG Code: 1852	CRS name: Tuple 1	Timbalai 1948
CRS Type	Geocentric CRS		CRS Type	Geocentric CRS
EPSG Code	4978		EPSG Code	N/A
X	-2520611.579		X	-2519949.917
Y	5838605.450		Y	5837972.037
Z	486048.455		Z	486099.602
CRS name: Tuple 2	WGS 84		CRS name: Tuple 2	
CRS Type	Geographic 2D CRS		CRS Type	Geographic 2D CRS
EPSG Code	4326		EPSG Code	
Latitude	04° 23' 59.678" N		Latitude	04° 24' 02.534" N
Longitude	113° 21' 02.03681" E		Longitude	113° 20' 50.475" E
CRS name: Tuple 3	WGS 84 / UTM zone 49N		CRS name: Tuple 3	Timbalai 1948 / RSO Borneo (ftSe)
CRS Type	Projected 2D CRS		CRS Type	Projected 2D CRS
EPSG Code	32649		EPSG Code	29872
Easting	760866.20		Easting	1335086.59
Northing	486742.59		Northing	1596931.05
Vertical CRS	msl height		Vertical CRS	msl height
CRS Type	Vertical		CRS Type	Vertical
EPSG Code	5714		EPSG Code	5714
H	N/A		H	54.23

Are correct precision values passed on to drilling?



What size of uncertainties can be tolerated at tie-point to achieve target objectives?

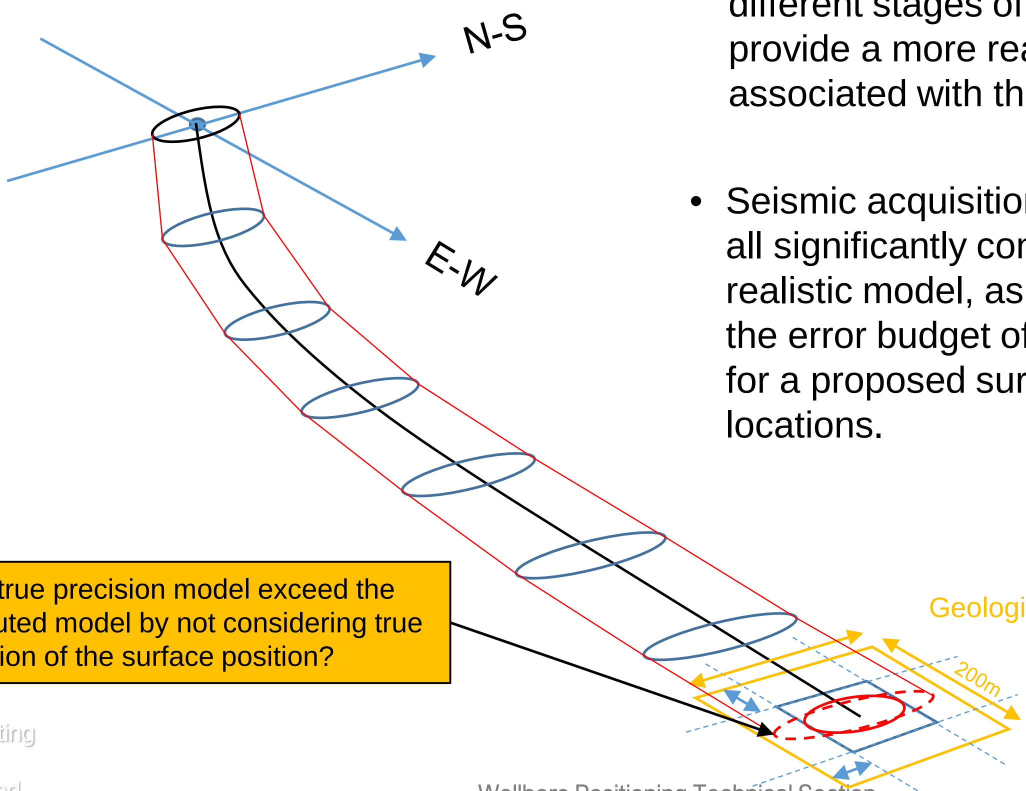
Derived from seismic trace data

Questions?

- Total precision associated with the coordinates of the tie-in point. Is it known and applied? Taken from positioning technologies of rig move only?
- Is its precision sufficiently described to achieve the precisions required for the drillers target at final bottom hole location?

What is the truth of tie-in uncertainties?

Or is it more like this?



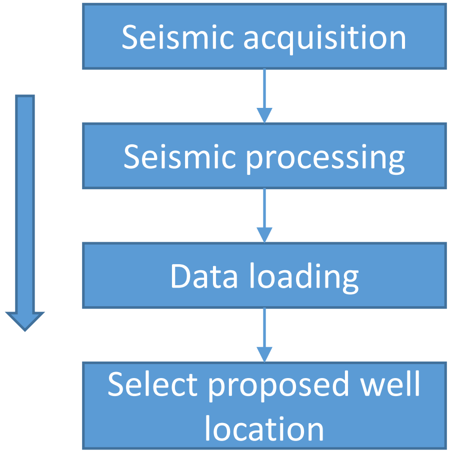
- Understanding errors that propagate through the different stages of the exploration cycle aims to provide a more realistic answer to the precisions associated with the tie-in position.

- Seismic acquisition, processing and data loading all significantly contribute to create a more realistic model, as they all naturally contribute to the error budget of the trace locations selected for a proposed surface and target drilling locations.

Does true precision model exceed the computed model by not considering true precision of the surface position?

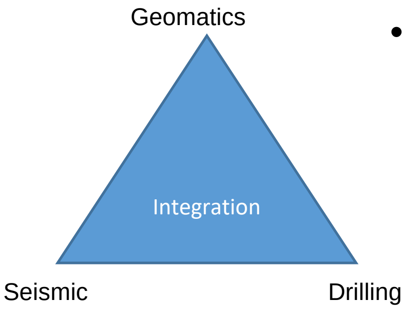
Agenda for today – stage one of study

Consideration of the propagation of errors that will impact the precision with which the coordinates of a proposed well location (well header), tie-in point are described.



- Error has to propagate from one process to the next. Just because one process is completed, prior to another one commencing, does not trigger a reason to reset the error counter back to zero.

- How is it realistic propagated? What impact will this have upon the precision of the coordinates of the proposed well location.

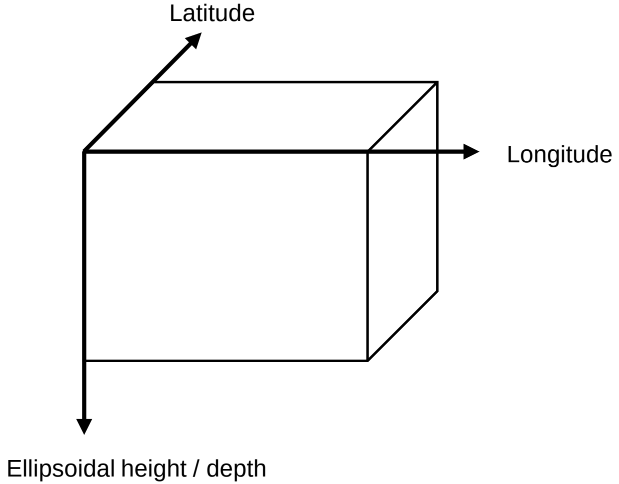


- General demonstration that the observations and processing techniques are shared between different disciplines, which will benefit in creating a unified model.

Unified coordinate reference system

- A unified model requires, where possible, all stages of activity are referenced to the same coordinate reference system (CRS).

- Exploration activity is three dimensional and therefore should adopt a three dimensional CRS that shall supersede the long established practice of using two-dimensional horizontal CRS, combined with a one-dimensional vertical CRS.



Local CRS versus Global CRS?

- Also spare a thought for this issue. To convert positions between a source and target CRS a coordinate operation is invoked: The coordinate transformation.

- What errors are being introduced to the data by performing a coordinate transformation? Is this a measurable quantity?

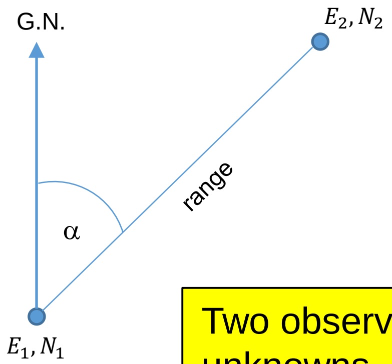
Back to basics: theory is the same

- Whenever observations are made as part of any survey campaign errors are introduced.

- As a minimum these will be random errors, but may also contain systematic and gross errors too.

- Random error cannot be measured. We can only assign a value to it with a certain degree of probability $(1\sigma, 2\sigma)$.

- If observations contain error then so too will the coordinates of the survey nodes whose positions are being derived (Gaussian propagation).



Two observations, two unknowns, no redundancy. Cannot detect gross errors.

The same basic rules apply throughout all exploration stages and accumulate phase by phase.

Computational Technique(s)

To compute unknown parameters values (e.g. positions) from the raw observations an estimation technique is required. The preferred method used by surveyors / geomatics is the **least squares adjustment** (or a more advanced version – Kalman Filter).

The least squares estimate of the normal equations is described by:

$$\boxed{\hat{x} = [A^T W A]^{-1} A^T W b}$$

Where:

$\hat{x}$ = Vector of unknown parameters

A = Functional model / Design matrix

W = Stochastic model / Weight matrix

b = Observed – computed measurements

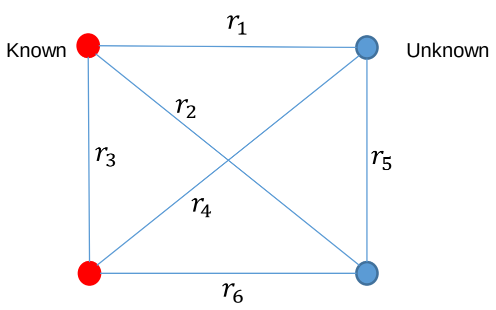
- Nowadays all LSA are weighted, which provides a formal way of estimating the amount of error in the observations.

- The beauty of this is if we ‘know’ or ‘estimate’ the accuracy of the observations we can derive the accuracy of the unknown parameters from covariance matrix, $C_{\hat{x}}$.

$$\boxed{C_{\hat{x}} = (A^T W A)^{-1}}$$

Functional model / Design matrix

Functional model describes the geometric relationship between the observation scheme and the unknown parameters. Consider a very basic four node network as per acoustic positioning network:



Observation equations:

$$r_1 = [(E_2 - E_1)^2 + (N_2 - N_1)^2]^{1/2}$$

As the expression is non-linear it must be linearized by partially differentiating each parameter with respect to the function (r), e.g.

$$\frac{\partial r_1}{\partial E_2} = \frac{(E_2 - E_1)}{r}$$

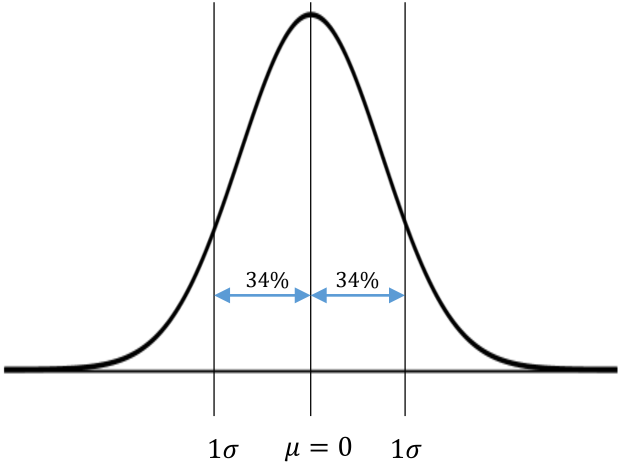
$$A = \left[\begin{bmatrix} \frac{\partial F_1}{\partial x_1} & \cdots & \frac{\partial F_1}{\partial x_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial F_n}{\partial x_1} & \cdots & \frac{\partial F_n}{\partial x_n} \end{bmatrix}\right]$$

This creates the individual elements for the Jacobian matrix A. One row for each observation, one column for each unknown parameter.

Stochastic model / Weight matrix

- Formal way of describing how much random error is expected to occur in each observation type used in the LSA, e.g. the precision of each observation. The higher the precision, the more those observations contribute to the solution.
- First, describe the ***apriori*** covariance matrix of the observations, C_l. The diagonal terms are the variances, σ_n^2, the off-diagonals are the covariance terms, σ_{nm}.

$$C_l = \begin{bmatrix} \sigma_1^2 & \cdots & \sigma_{1n} \\ \vdots & \ddots & \vdots \\ \sigma_{n1} & \cdots & \sigma_n^2 \end{bmatrix}$$



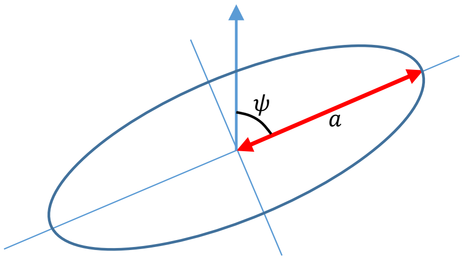
- Next, compute the stochastic model by taking the inverse of each variance term. In practice, the covariance terms are ignored.

$$W = \frac{1}{C_l} \Rightarrow W = \begin{bmatrix} \frac{1}{\sigma_1^2} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \frac{1}{\sigma_n^2} \end{bmatrix}$$

A posteriori covariance matrices, $C_{\hat{x}}$ and $C_{\hat{v}}$

- Aposteriori covariance matrices describe the precision of the parameters derived from the least squares adjustment, namely:
- **Covariance matrix of $\hat{x}$**, $C_{\hat{x}}$ is given by: $C_{\hat{x}} = (A^T W A)^{-1}$
- **Covariance matrix of $\hat{v}$**, $C_{\hat{v}}$ is given by: $C_{\hat{v}} = W^{-1} - A(A^T W A)^{-1} A^T$

$$C_{\hat{x}} \begin{bmatrix} \sigma_{E_1}^2 & \sigma_{EN} & 0 & 0 & 0 & 0 & 0 \\ \sigma_{NE} & \sigma_{N_1}^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sigma_{E_2}^2 & \sigma_{EN} & 0 & 0 & 0 \\ 0 & 0 & \sigma_{NE} & \sigma_{N_2}^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & .. & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma_{E_n}^2 & \sigma_{EN} \\ 0 & 0 & 0 & 0 & 0 & \sigma_{NE} & \sigma_{N_n}^2 \end{bmatrix}$$



- Notice that neither $C_{\hat{x}}$ nor $C_{\hat{v}}$ depends upon the vector b.
- By using *A* and *W* the quality of the parameters can be made without any knowledge of the actual observations.

Gauss's law of covariance propagation

- Consider the matrix equation, where p and q are stochastic vectors and *A* is their deterministic relationship, therefore:

$$\boxed{p = A.q}$$

- If C_q is the covariance matrix of q, then C_p is the covariance of p and can be determined from:

$$\boxed{C_p = A^T C_q A}$$

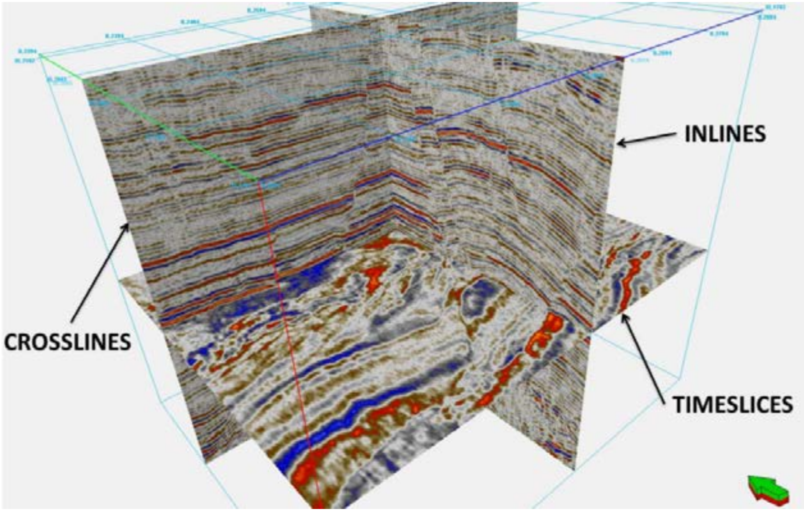
- Of what relevance is this law? It enables the accuracy or precision of one quantity to be determined from another. This creates a chain of dependencies that propagate through the different stages of the exploration cycle.

- The development of our 'new' error model will endeavour to propagate the errors from one stage the next, with the ultimate goal of trying to determine what the 'true' errors (the precision) will be for the coordinates of the drill bit at the target location.

Zinn 1990

Seismic acquisition and data processing

- Seismic trace data paints the pictures of the subsurface.
- The resolution of the imaging is governed by the geometry of sources and receivers deployed during data acquisition.
- A key deliverable from seismic acquisition are the coordinates derived for the source and receiver locations.

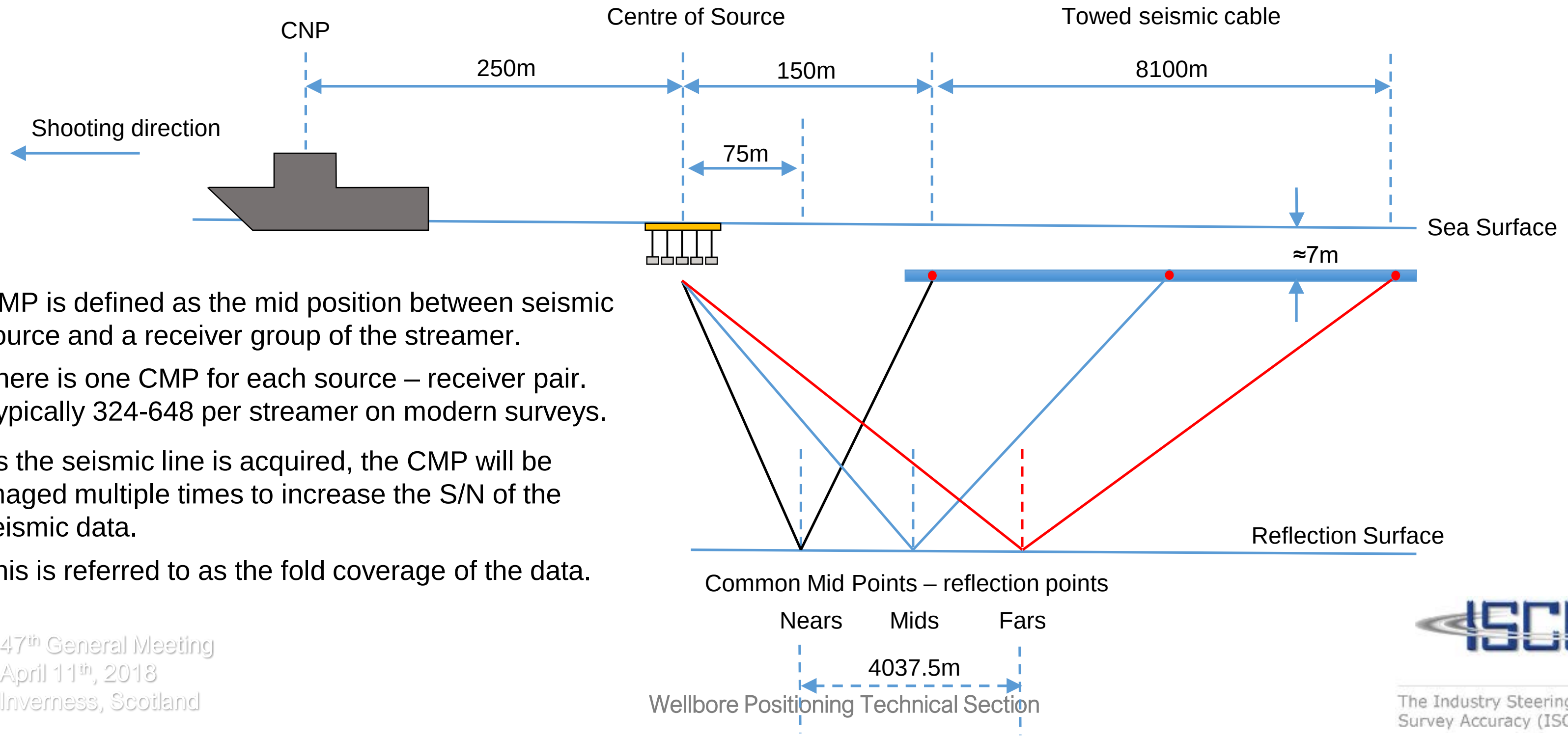


- These in turn will determine how the seismic data ‘stacks’ together in data processing and what coordinates are eventually assigned to the trace data. To date, scare attention has been paid to assigning meaningful quality measures to these data types.

Therefore, the first stage in our quest is to determine the precision with which the seismic trace data can be derived. To achieve this the horizontal mid point accuracy of the traces is examined.

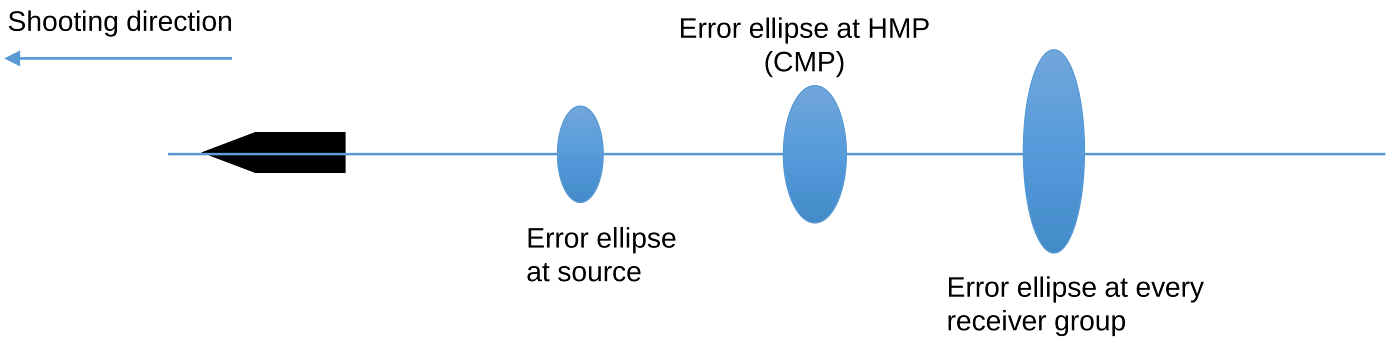
Seismic acquisition – HMP precision estimates

What follows is an example of how this applies to seismic acquisition. Many different acquisition methods are regularly used. However, this example uses the more common towed marine seismic configuration.



- CMP is defined as the mid position between seismic source and a receiver group of the streamer.
- There is one CMP for each source – receiver pair. Typically 324-648 per streamer on modern surveys.
- As the seismic line is acquired, the CMP will be imaged multiple times to increase the S/N of the seismic data.
- This is referred to as the fold coverage of the data.

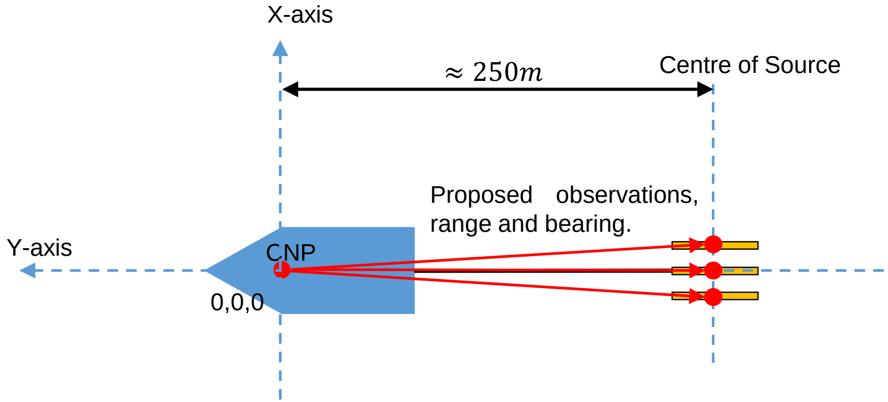
Horizontal mid point accuracy?



- Gaussian propagation of errors: ‘propagates’ error from the source and receiver group positions into error at the HMP (CMP) position.
- Therefore, size of the SMA of the HMP error ellipse will be an average of those computed for the source or receiver group.
- To start, the precision with which the source and receiver positions can be determined must be examined.

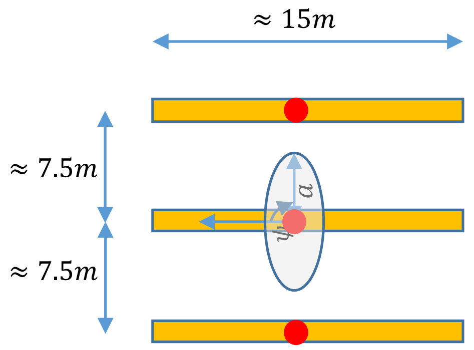
Source positioning

- To determine position of the geometric center of source of the seismic array(s) at the time of shot.



Today, rGPS is standard technology. Historically, this was achieved with lasers and acoustics.

Accuracy with which the center of source is described is a function of observation geometry and *apriori* random error estimates.

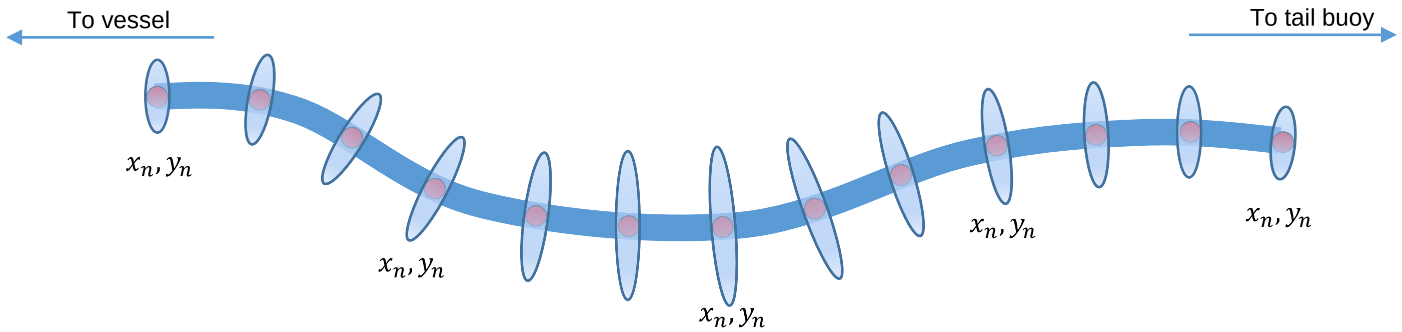


Error ellipse computed from $C_{\hat{x}}$, to determine semi major axis and orientation. Cross line precision will exceed in-line precision.

Receiver positioning

Likewise, accuracy with which the center of each receive group is described is a function of observation geometry and *apriori* random error estimates.

Braced acoustic networks form basis of modern surveys. Historically, magnetic compasses and radio positioning were employed.

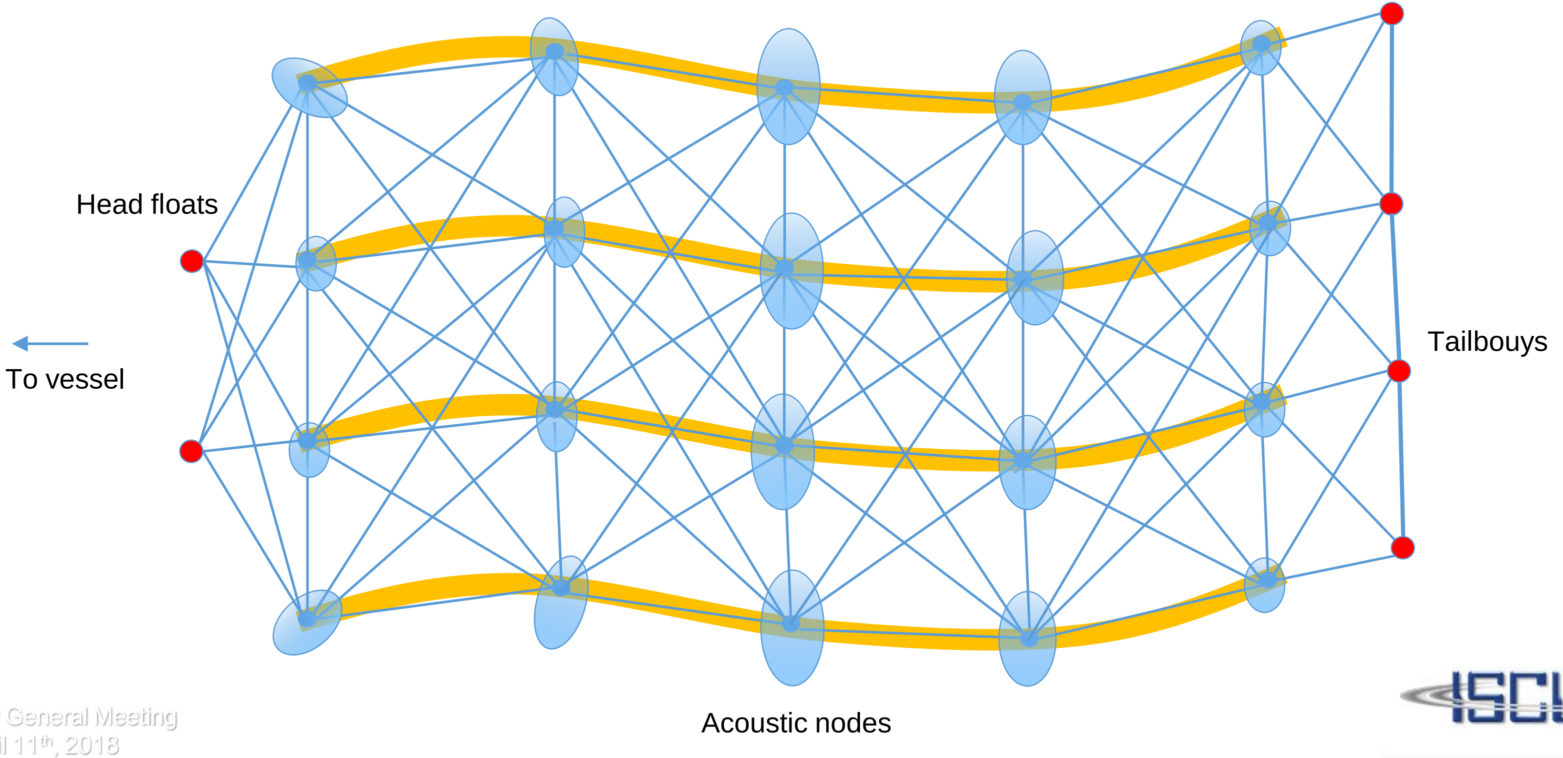


Error ellipses are initially derived from $C_{\hat{x}}$ for acoustic nodes within the network, which enables the precision of each receiver group to be interpolated.

Precision will deteriorate towards the mid sections of each streamer because of the geometric considerations of the network (e.g. distance from 'fixed' stations).

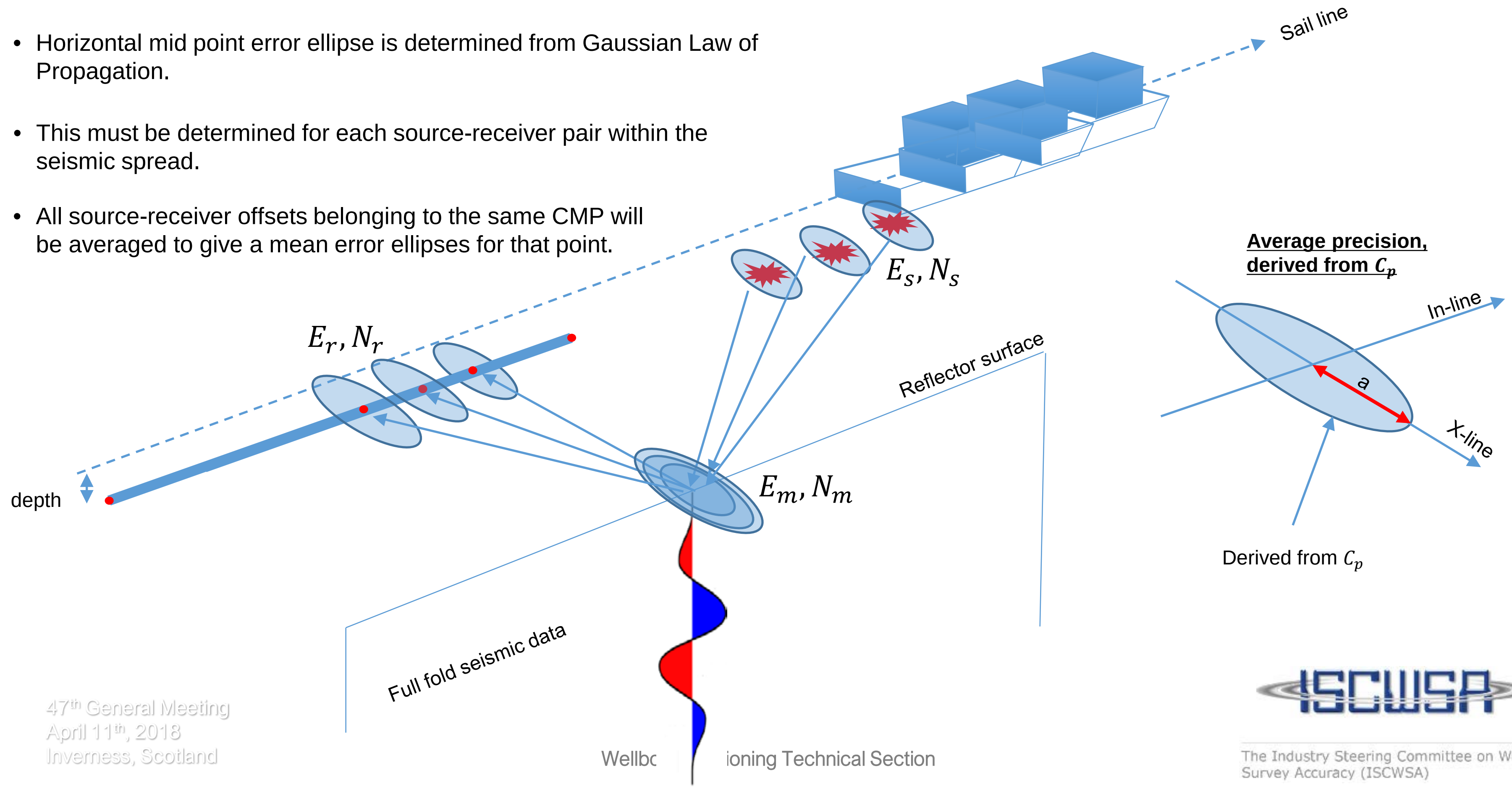
Acoustic network positions

Simplified acoustic network.



Horizontal mid point accuracy

- Horizontal mid point error ellipse is determined from Gaussian Law of Propagation.
- This must be determined for each source-receiver pair within the seismic spread.
- All source-receiver offsets belonging to the same CMP will be averaged to give a mean error ellipses for that point.



Gaussian Law of Covariance Propagation - HMP

Remembering: $p = A.q$ And: $C_p = A^T C_q A$

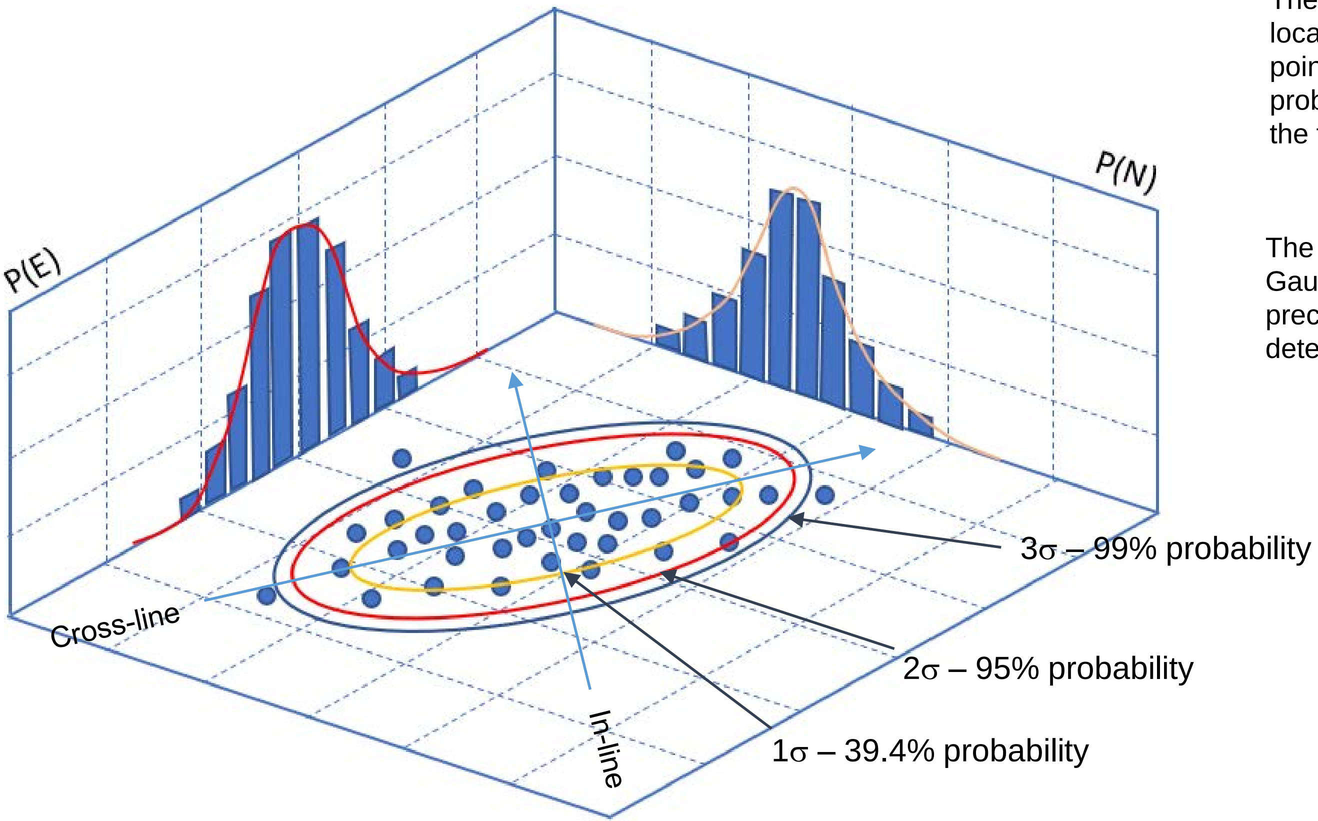
If: $q = \begin{bmatrix} E_s \\ N_s \\ E_r \\ N_r \end{bmatrix}$ Then: $C_q = \begin{bmatrix} \sigma_{E_s}^2 & \sigma_{E_s N_s} & 0 & 0 \\ \sigma_{E_s N_s} & \sigma_{N_s}^2 & 0 & 0 \\ 0 & 0 & \sigma_{E_r}^2 & \sigma_{E_r N_r} \\ 0 & 0 & \sigma_{E_r N_r} & \sigma_{N_r}^2 \end{bmatrix}$

Therefore: $C_p = \begin{bmatrix} \sigma_{E_m}^2 & \sigma_{E_m N_m} \\ \sigma_{E_m N_m} & \sigma_{N_m}^2 \end{bmatrix}$ For each source-receive pair

This is computed for all source-receiver offsets, which in turn need to be averaged for all source-receiver offsets belonging to the same CMP gather.

$$C_{p_r} = \frac{\sum_1^n \begin{bmatrix} \sigma_{E_m}^2 & \sigma_{E_m N_m} \\ \sigma_{E_m N_m} & \sigma_{N_m}^2 \end{bmatrix}}{n}$$

Precision of the trace data



The trace is always considered to be located at the centre of the common mid point 'bin'. However, there is a 95% probability it can fall anywhere within the footprint of the ellipse.

The covariance matrix, $C_{\hat{x}}$, plus Gaussian propagation law enable the precision of the trace data to be determined in a more realistic fashion.

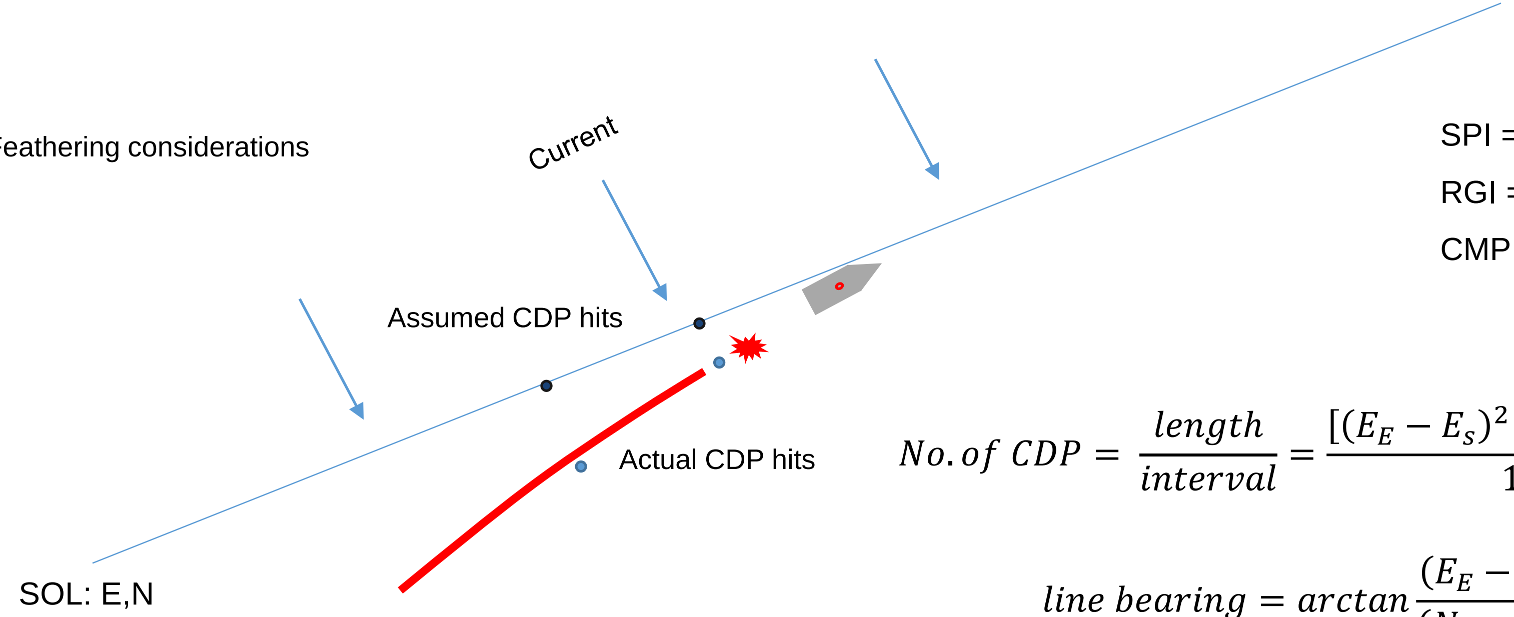
If:

$$1\sigma:\ a = \pm 5.5\ m$$

$$2\sigma:\ a = \pm 13.46\ m$$

Seismic processing - interpolation

Feathering considerations



SPI = 25m

RGI = 25m

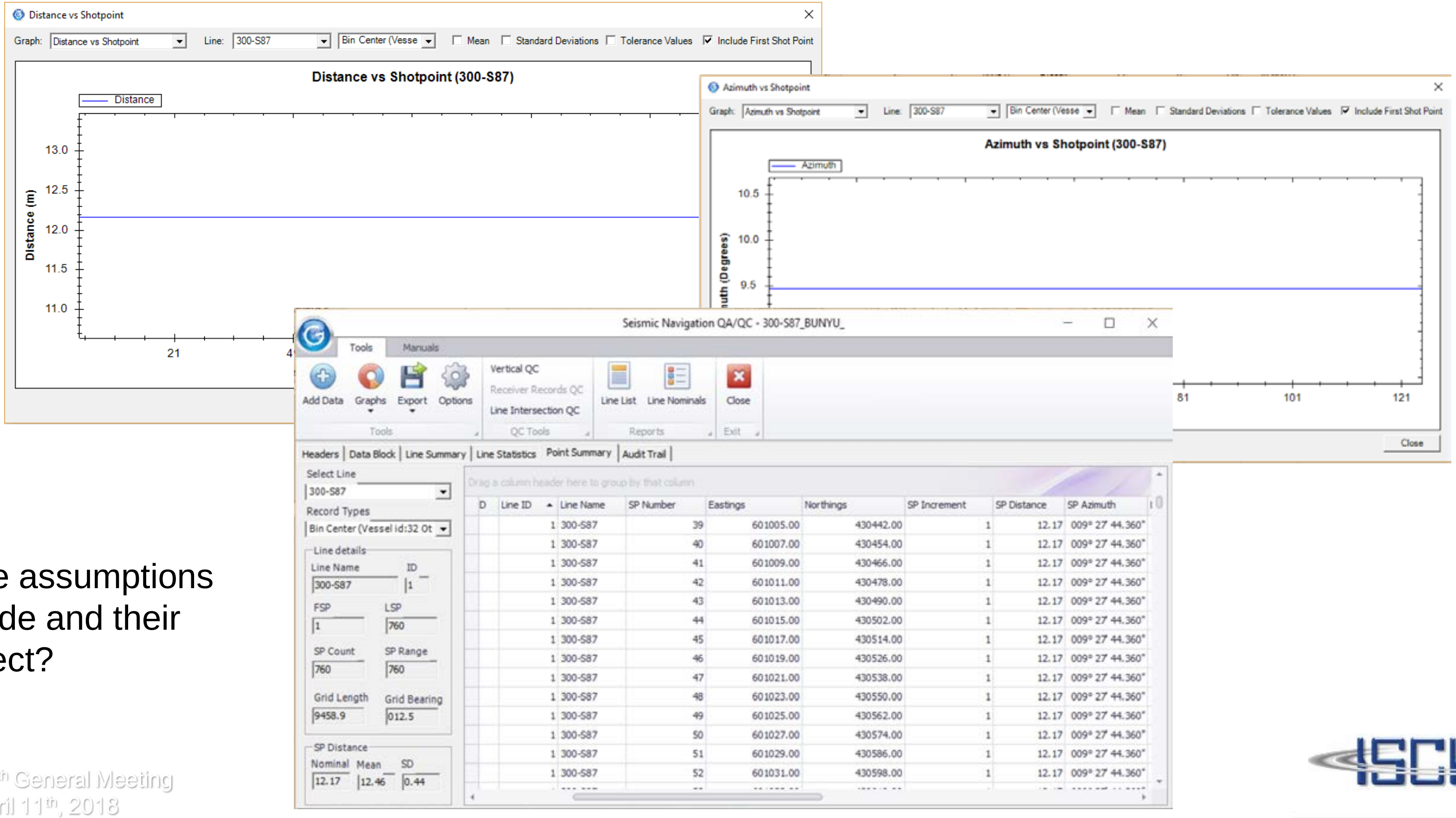
CMP = 12.5m

$$No.of\ CDP = \frac{length}{interval} = \frac{\left[(E_E - E_s)^2 + (N_E - N_S)^2\right]^{1/2}}{12.5}$$

$$line\ bearing = arctan\frac{(E_E - E_S)}{(N_E - N_s)}$$

Trace positions interpolated between SOL and EOL at 12.5m intervals along a bearing computed using the SOL and EOL coordinates. Therefore, trace data is assumed to occur on the pre-plot line. This is very seldom the case. What effect on precision?

2D seismic data processing – interpolation

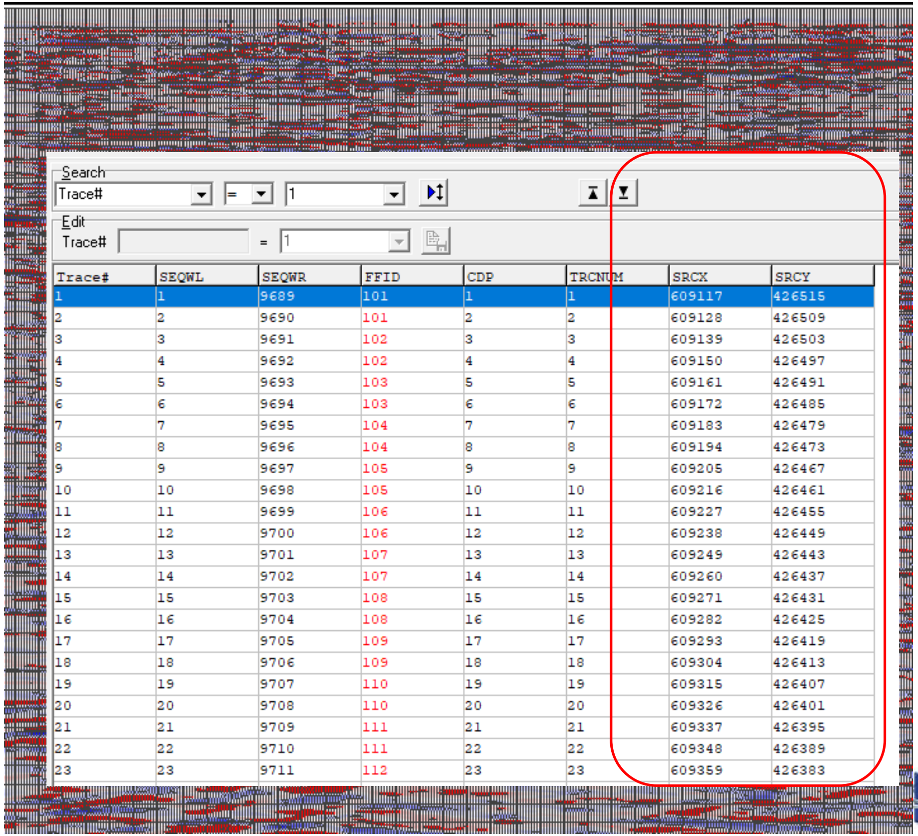


The assumptions made and their effect?

Interpolated coordinates – trace headers

Traces – vertical lines.

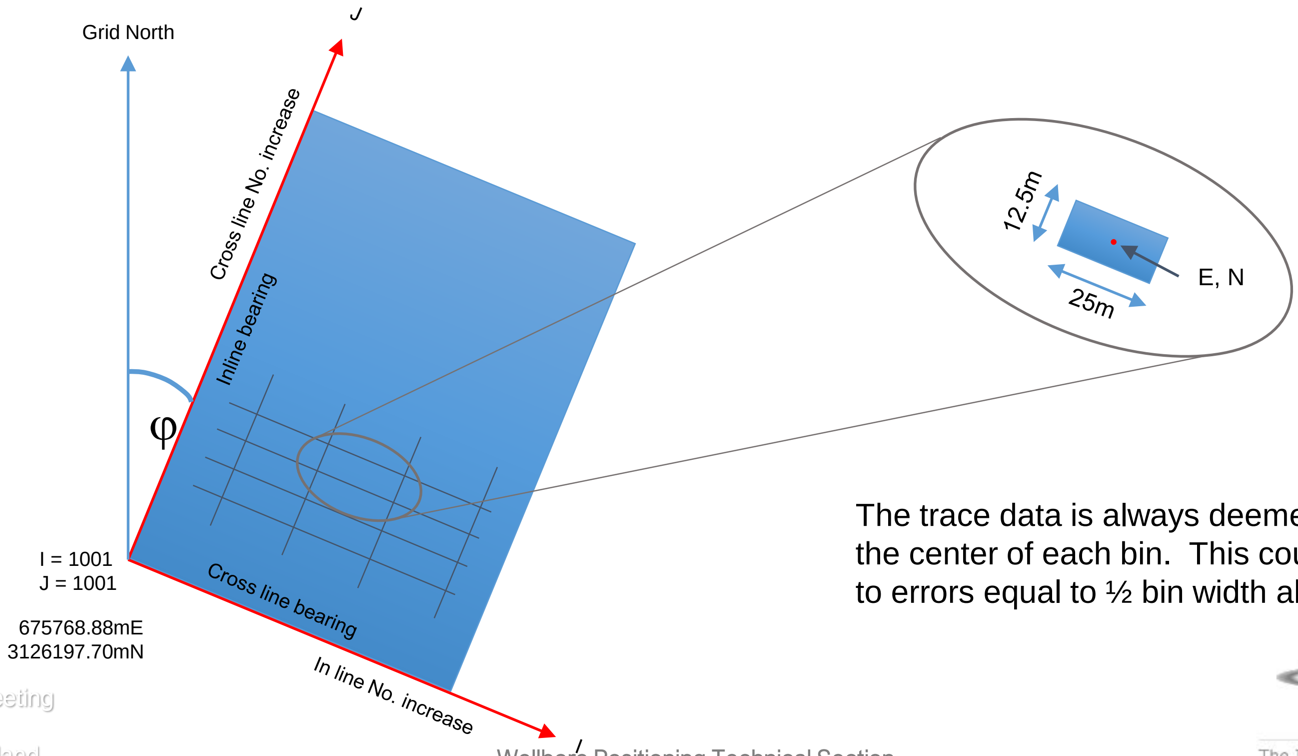
- Each trace is assigned a position, whose coordinates are given referenced to a projected 2D coordinate reference system. If known??
- Coordinates are not exact and contain error. Amounts of error (or their precision) cannot be stored within any of the file formats currently defined, with one exception, P1/11.



Trace#	SEQWL	SEQWR	FFID	CDP	TRCNUM	SRCX	SRCY
1	1	9689	101	1	1	609117	426515
2	2	9690	101	2	2	609128	426509
3	3	9691	102	3	3	609139	426503
4	4	9692	102	4	4	609150	426497
5	5	9693	103	5	5	609161	426491
6	6	9694	103	6	6	609172	426485
7	7	9695	104	7	7	609183	426479
8	8	9696	104	8	8	609194	426473
9	9	9697	105	9	9	609205	426467
10	10	9698	105	10	10	609216	426461
11	11	9699	106	11	11	609227	426455
12	12	9700	106	12	12	609238	426449
13	13	9701	107	13	13	609249	426443
14	14	9702	107	14	14	609260	426437
15	15	9703	108	15	15	609271	426431
16	16	9704	108	16	16	609282	426425
17	17	9705	109	17	17	609293	426419
18	18	9706	109	18	18	609304	426413
19	19	9707	110	19	19	609315	426407
20	20	9708	110	20	20	609326	426401
21	21	9709	111	21	21	609337	426395
22	22	9710	111	22	22	609348	426389
23	23	9711	112	23	23	609359	426383

Bin grid definitions – modern 3D surveys

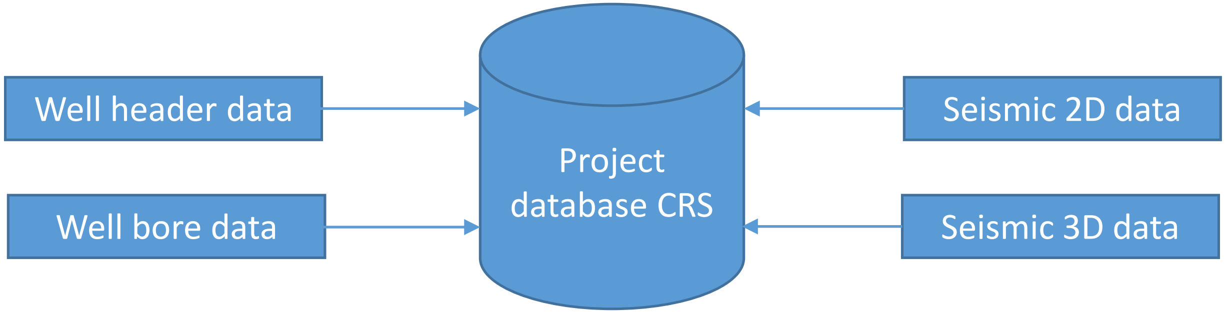
- Precisions computed for the trace locations should be carried over to the processing stage, where the same precision levels should exist under normal situations. Other considerations include:



The trace data is always deemed to be deleted at the center of each bin. This could potentially lead to errors equal to ½ bin width along both axes.

Data loading to interpretation station

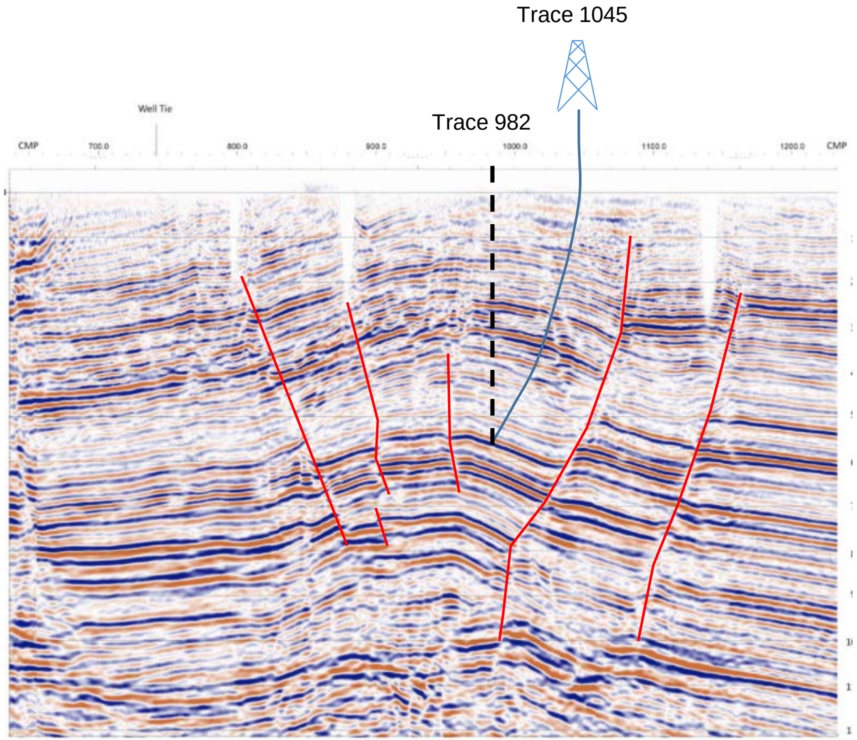
Although this stage does not necessarily induce a degradation of precision based upon a computation (unless a coordinate transformation is performed), it does require that data loaders protect data integrity by honouring the metadata associated with the data types being imported.



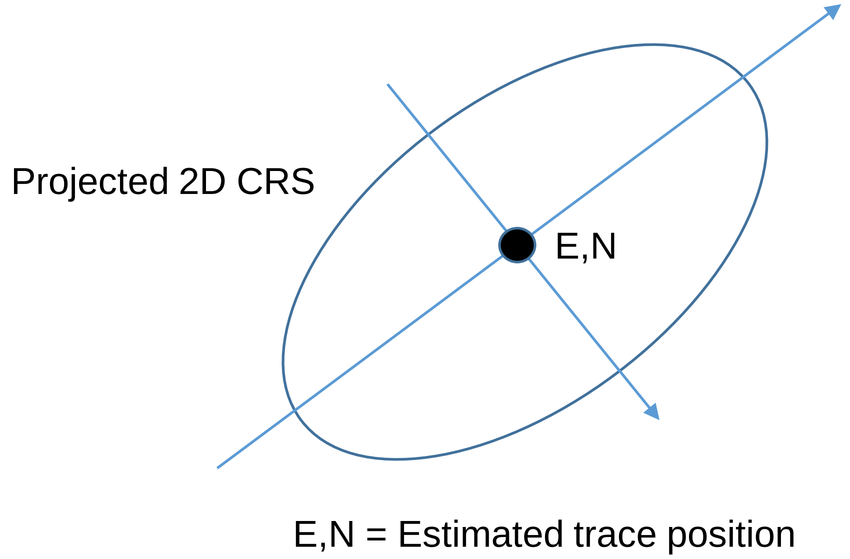
Maintaining integrity requires data loaders select the correct parameters for the data. Most importantly selecting the CRS associated with the data. Incorrect choice may introduce horizontal error with a magnitude of many hundreds of meters. This will have a direct impact on the proposed well header coordinates.

Proposed well location - precision

- Geological target and surface location are both selected from the static model interpretation.
- Locations will be identified in terms of the in-line and cross-line numbers associated with the seismic traces.
- Coordinates related to projected 2D CRS and geographic 2D CRS are assigned to the traces along with target depth.
- Coordinates must have related precision measure assigned to them.



Surface and target positions - trace data



- The seismic trace positions linked with both target and surface locations must have precision measures formally estimated.
- Precision measures should be formally passed on to the next stages of the exploration cycle using a model incorporating the correct deterministic model of the gaussian covariance propagation.

Conclusion

- It is currently believed that seismic exploration activities are not satisfactorily broadcasting its precision measures to subsequent stages of the exploration cycle.

- Correct seismic covariance error modelling is required to describe the starting error model for the next stages.

- Starting error at the next stages does not automatically get set to zero and ignore errors already accumulated.