

MEC™-Pipe Crawler FLEXIBLE RISER INSPECTION REPORT

Client: Client a

Facility: Site FPU

Items Inspected: 13" Flexible Riser

Inspection Method: MEC™-FIT technology

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13" Flexible Riser FLEXIBLE PIPE INSPECTION REPORT

Using MEC™-FIT

Prepared for


Client a

Final Report: K0xx-15

Rev	Document	Author		Checked		Approved By		Date
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1. Executive Summary

The inspection of the 13" Flexible Riser at the site FPU was carried out on September 19th and 20th 2015. A total of 45 m was inspected starting at the mid-water arc buoyancies through the sag bend towards the FPU.

Several indications of residual stresses in the wire structures have been found. Cracked wires have not been found.

2. Inspection Execution

2.1. Task

Innospection Ltd. has been contracted by Client a to inspect the 13" Flexible Riser at the site FPU in the x Sea. The MEC™-FIT technology was to be used for the inspection to find crack-like defects in the inner and outer layer. The area to be inspected was from the buoyancy of the mid-water arc upwards towards the FPU. The length to be inspected was 58 m.

The suitability of the method has been established by extended in-house testing (ER.155.02TestResultsRev02) and was demonstrated to the client by an acceptance blind test on July 10th 2015.

The technology was built into the MEC™-Pipe Crawler tool (ref. 2.3). It was attached to the pipeline using an Inspection class ROV supplied by company a.

2.2. Inspection Object

The site FPU is located in the block 00/00x in the x Sector of the x Sea.



Figure 1: The FPU

The riser consisted of a two layer 55°-wire structure. No Zeta-wire or other structure was present to take the hoop stress. The details of the riser structure are given in Table 1.

No	Layer Type	Layer Thickness [mm]	OD [mm]
1	Interlocked carcass	10	350.2
2	Rilsan Pressure Sheath	11	372.2
3	Inner Armour layer at 55 deg	5	382.2
4	Rilsan anti-wear tape	2.5	387.2
5	Outer Armour layer at -55 deg	5	397.2
6	Fabric tape	2.3	401.8
7	Rilsan External Sheath	13	427.8

Table 1: Layer set-up of the Flexible Riser

What made the task special in this project was the 55°-structure. Regular axial scanning is not possible with a 55° structure. The adjacent gaps in between the wires would generate signals that will mask signals from cracks or other defects. The tool had to be set-up to scan in the circumference. In addition the outer sheath thickness of altogether 15.3 mm is relatively high.

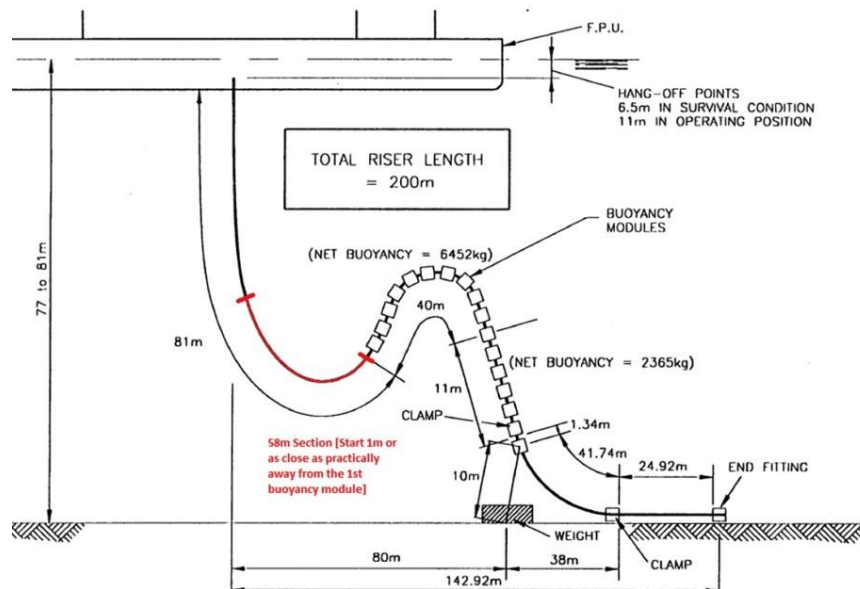



Figure 2: Section of the 13" Oil Export Riser to be inspected

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2.3. Equipment

The MEC™-FIT inspection technology (a further development of the Saturation Low Frequency Eddy Current) was used. For the subsea deployment a suitable tool (MEC™-Pipe Crawler) was designed and built. The inspection system consists of a crawler with eddy current sensors and a magnetization unit as the main parts. The crawler is connected via an umbilical (20 m) to the ROV, which transmits the acquired data to the vessel deck. Once attached to the pipeline the inspection tool moves by itself longitudinally and circumferentially using a hydraulic system.

The MEC™- Pipe Crawler tool has the following technical parameters:

MEC™- Pipe Crawler Tool:	Hydraulically driven crawler to be attached to a horizontal or vertical pipe from the outside. The scan diameter is adjustable. The tool weight is 215 kg in air / 7 kg in water, the tool size is 1200 mm x 510 mm x 1000 mm (L x H x W).
Sensors:	Eight Sensors of type FIT22. The unit covers a circumferential width of 180 mm. A switchable permanent magnet is used as magnetisation unit.
Scanning Speed:	Dependant on hydraulic flow. Typical circumferential speed: 3.5 cm/s or 2.1 m/min
Software Version:	Innospectit Version 2.51 (bespoke Version)

For more detailed information on the MEC™-Pipe Crawler system refer to Section 4.

2.4. Mobilisation and Preparation


Inspection Team

The inspection team was made up of two groups working 12h shifts. For the night shift this was:

Technician a, NDT Level II Eddy Current Inspection Engineer
 Technician b, Inspection Technician
 Technician c, Inspection Technician

For the day shift the team consisted of

Engineer a, Team Leader and Project Manager
 Technician d, Inspection Technician
 Technician e, NDT Level II Eddy Current Inspection Engineer

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Procedure for Calibration and Set-up

A wet test at the third party location was carried out on 8th of September 2015. The purpose of the test was to trim the buoyancies and to test the attachment of the inspection module to the pipe and its motion on the pipe.

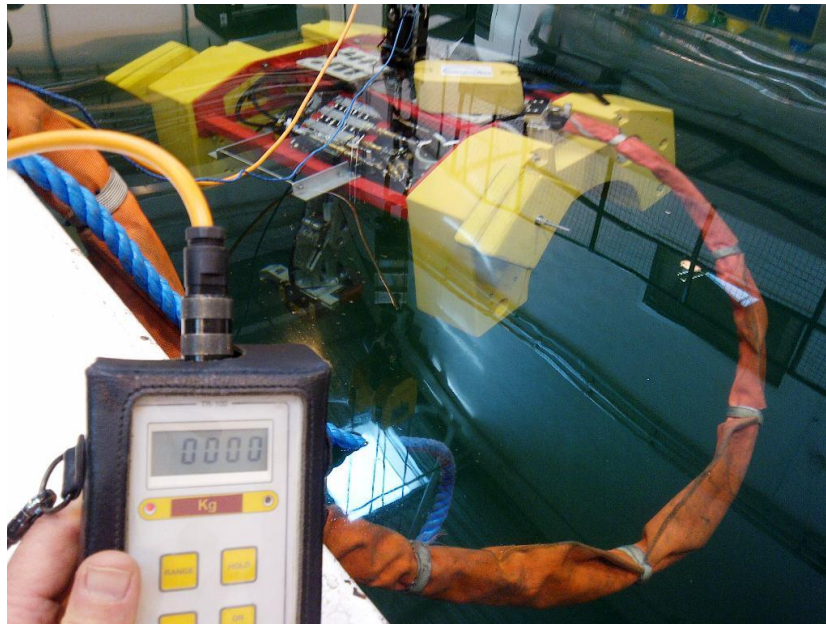


Figure 3: Several tests were carried out in the Third Party location. Here the net weight of the tool in water is measured.

The preparation and inspection of the riser was done according to Innospection's procedures

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- OP.150618abc-FlexibleRiser


The general test set-up was done prior to mobilisation in the workshop. All sensors have shown appropriate signals. The settings were done accordingly before the tool was launched.

Mobilisation Dates

The equipment has been mobilised on September 7th 2015. It was received back in the Aberdeen office on September 28th 2015.

Cleaning

The cleaning was carried out by third party supplier. It was done by mechanical scraping with a device colloquially called a "Cheese wire". It consists of a thread that is slid over the pipe surface using the ROV. The cleaning was successful resulting in a surface free of marine growth.

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2.5. Execution and Performance

Scanner Deployment and Movement

The crawler was deployed together with the ROV from topside. The ROV was a Saab SeaEye Falcon type inspection class ROV. The attachment to the Riser took several attempts. Additional buoyancy blocks had to be added to the crawler. After successful attachment the scanning procedure was started. It consisted of consecutive clockwise, counter clockwise and axial movement. The clockwise and counter clockwise rotation covered slightly more than 360° in order to ensure full coverage. Likewise the axial advancement covered in average a distance of 165 mm, which is less than the scanned width.

The distance encoder measured the travelled distance and saved the data with the inspection signals. The inspection data of one circular motion was saved into one file. The data of this coverage is called a "track" in the following.

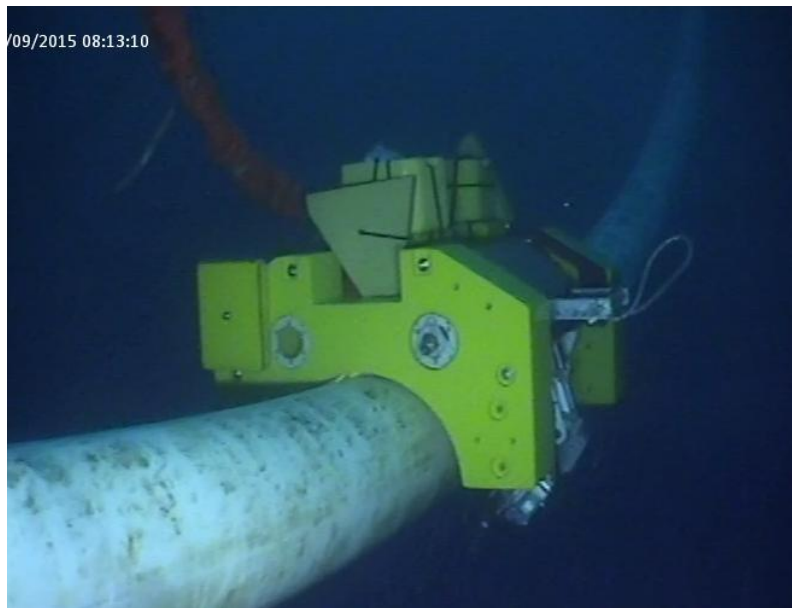


Figure 4: The MEC™-Pipe Crawler tool attached onto the 13" Flexible Riser. The position is near the low point of the arc.

The sequence of data acquisition was continued for two long scans. Initially shorter scans were envisaged, but due to time constraints this procedure was followed. In addition it was planned to have the clockwise track done with the magnet on and the reverse with the magnet off. It has turned out, that the tool did not attach well enough with the magnet off. Hence all tracks were done with the magnet on. The rotational speed was not constant at all times. The fact that the buoyancy was altered resulted in a misalignment of the center of buoyancy to the center of weight. The effect was a net torque on the tool. For the clockwise motion a slower speed at the 9 o'clock orientation and at the 3 o'clock orientation for the counter clockwise motion was the result. In severe cases the tool stopped for a short time.

The average speed was 0.035 m/s compared to the initially planned speed of 0.13 m/s. Refer to section "Data Quality" on how this was rectified.

Tracks and Coverage

The datum point is the start of the buoyancy modules of the arc. Note that there is a dead zone (i.e. unscanned distance) of about 360 mm between the physical position of the buoyancy and the data start point. This is set to distance 0 m with increasing distance upwards. It corresponds to 81 m as counted by the Client's 3D coordinates. The details of the two scans are shown in Table 2. The position is depicted in Figure 5.

Scan	From	To	Date/Time	No. of tracks
1	14039.0 m	44917.3 m	19.Sept.15 16:50 till 20.Sept.15 03:01	187
2	0 m	24729.6 m	20.Sept.15 03:33 till 20.Sept.15 11:16	151

Table 2: Coverage of the two scans

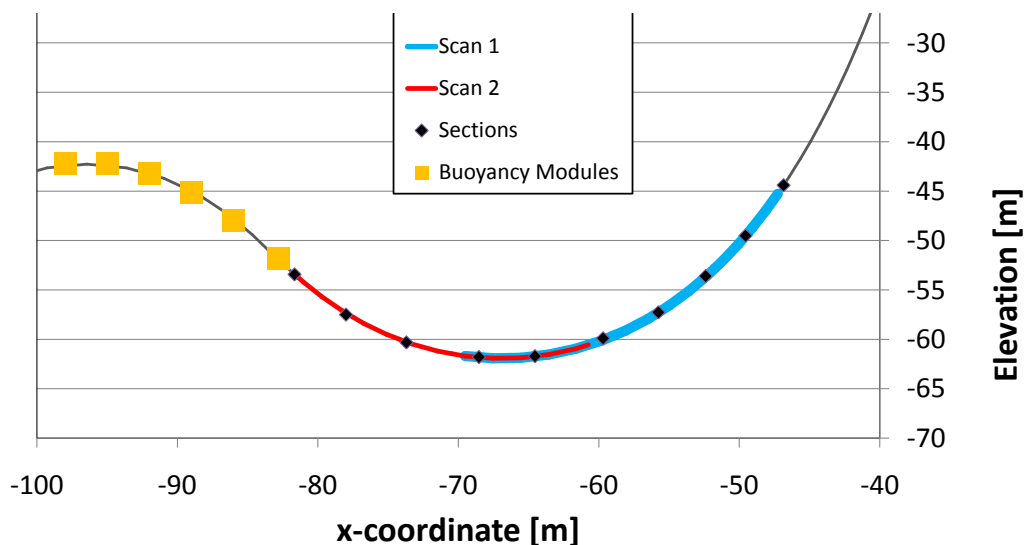


Figure 5: Position of the scans and section on the riser

For the purpose of analysis and reporting the length of the riser is segmented into 5 m sections. A section is covered by typically 31 tracks clockwise and 31 tracks counter clockwise. The first and the last track of a section are always copied into the adjacent section to guarantee a good picture. An overview of the sections is given in Table 3.

Section	Covered by scan No.	Start, [m]	End, [m]	No. of tracks
1	2	0	5	Scan 2: 31
2	2	5	10	Scan 2: 31
3	Partly 1 and 2	10	15	Scan 1: 6 Scan 2: 31
4	1 and 2	15	20	Scan 1: 31 Scan 2: 31
5	1 and partly 2	20	25	Scan 1: 31 Scan 2: 30
6	1	25	30	Scan 1: 31
7	1	30	35	Scan 1: 31
8	1	35	40	Scan 1: 31
9	1	40	45	Scan 1: 31

Table 3: Overview of sections


Data Quality

Several deviations from the intended scanning procedure required a treatment to the data in order to allow for a proper data analysis. The overall hydraulic flow was much lower than anticipated. The resulting speed was slower. This does not represent a problem. The speed has a strong influence on the required filter settings, but it is linear with the speed. The cut-off frequencies were adjusted by the factor of anticipated-to-required frequency ratio.

The speed was not constant. Due to the torque on the tool the crawler stopped at a specific orientation. The data at these positions is degraded and was not used. Due to the fact that the stopping positions were 180° apart the entire circumference was covered in total. The speed on the portion of the circumference that was used has shown sufficiently uniform motion.

The “magnet-off” data acquisition was not carried out. However, the main information is in the “magnet-on” data. All crack detection is done in the “magnet-on” configuration. The “magnet-off” is used for clear defect type discrimination and in particular discrimination of inner and outer layer. As the result of this inspection has shown, this was not of particular interest in this inspection.

There are a few spots, where the track data was not complete. It seemed that the programmable control has terminated the file data acquisition in a little too early time. The total portion of the data missing is less than 1 percent. Again there is a second data set of that position available.

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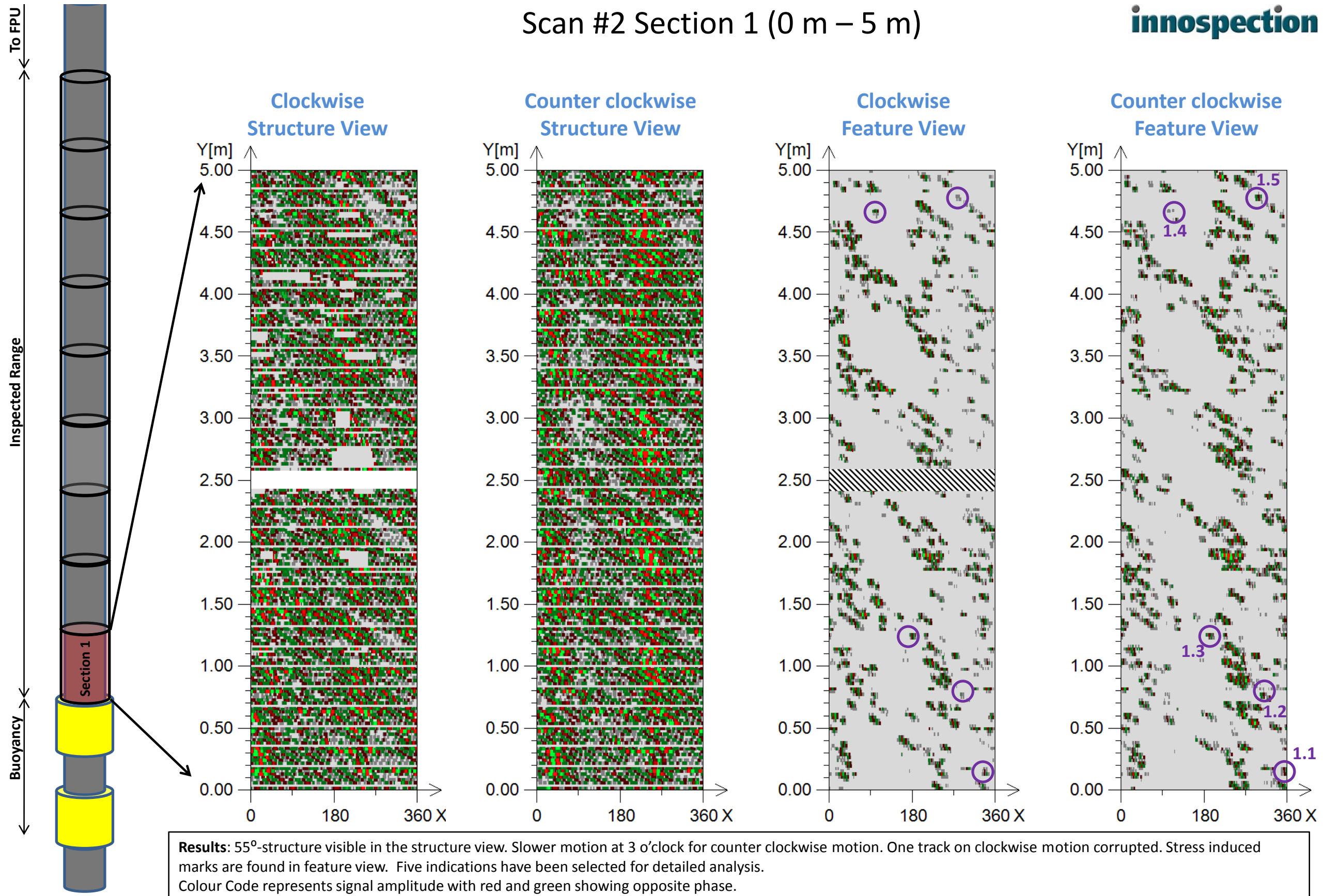
3. Results

3.1. Scan Result

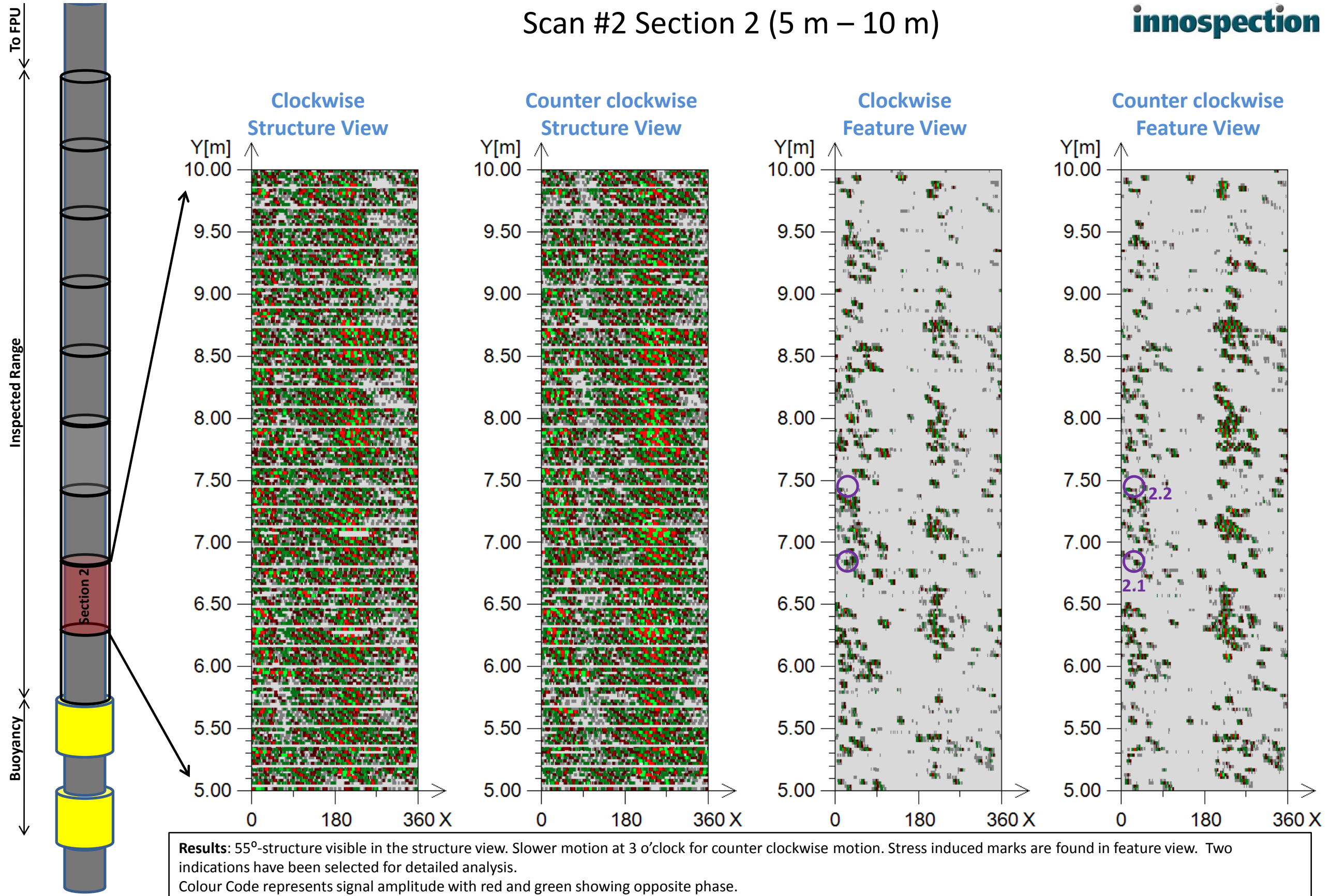
The following pages show the results of the scan. The results are shown as images with different views. Different views are selected by choosing different post processing parameters like gain, signal phase and time based filter settings. Different views allow visualisation of different features of the flexible pipe. The images on the left show the structure of the flexible. Stripes are visible that run from top left to bottom right. They have an inclination of 55°. The aspect ratio is not exactly 1:1 for better depiction of the structure.

The images on the right show the signal content that shows relevant features. The views show the clockwise and the counter clockwise scan. Note that for section 3, 4 and 5 there are two pages for the different scans.

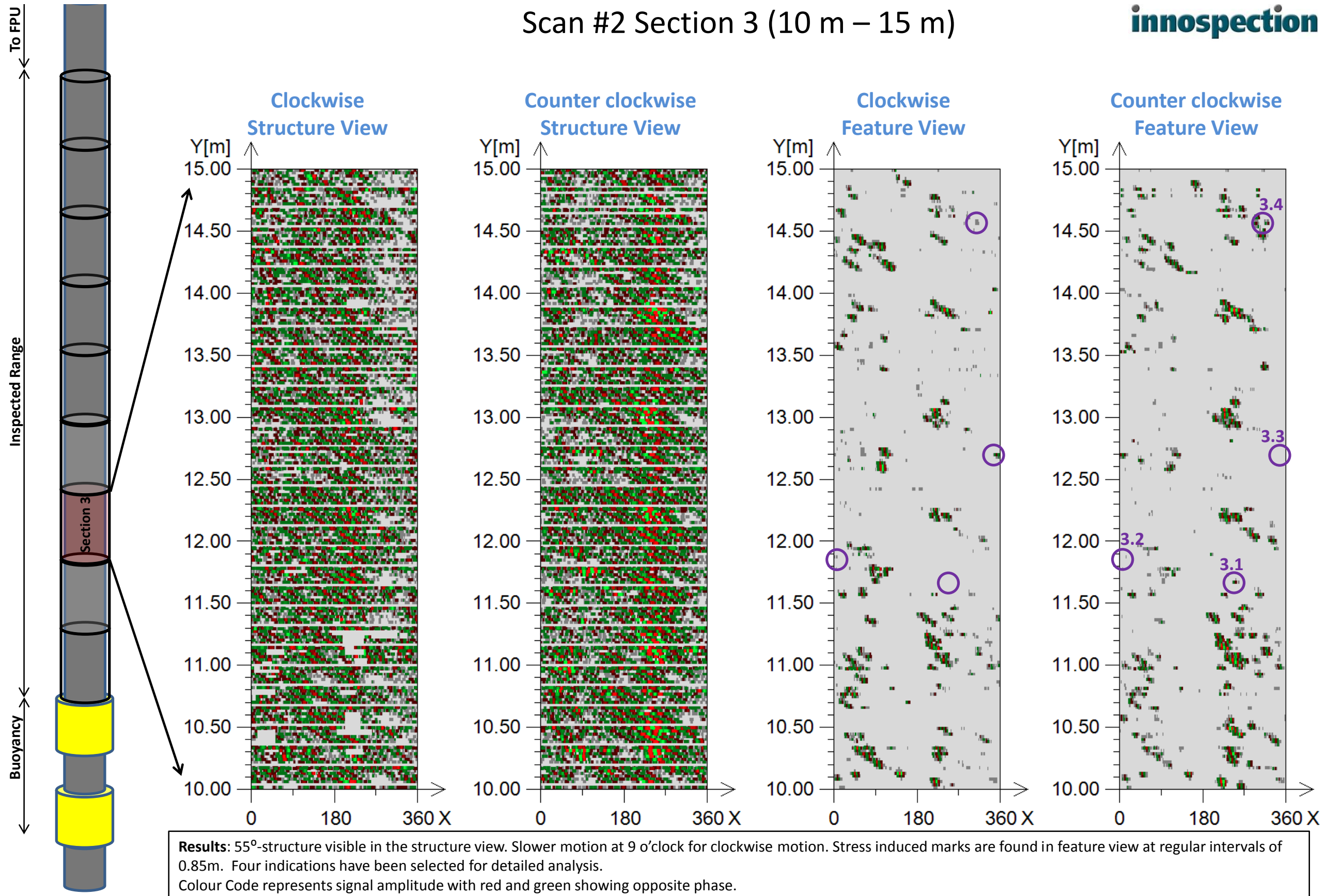
Scan #2 Section 1 (0 m – 5 m)



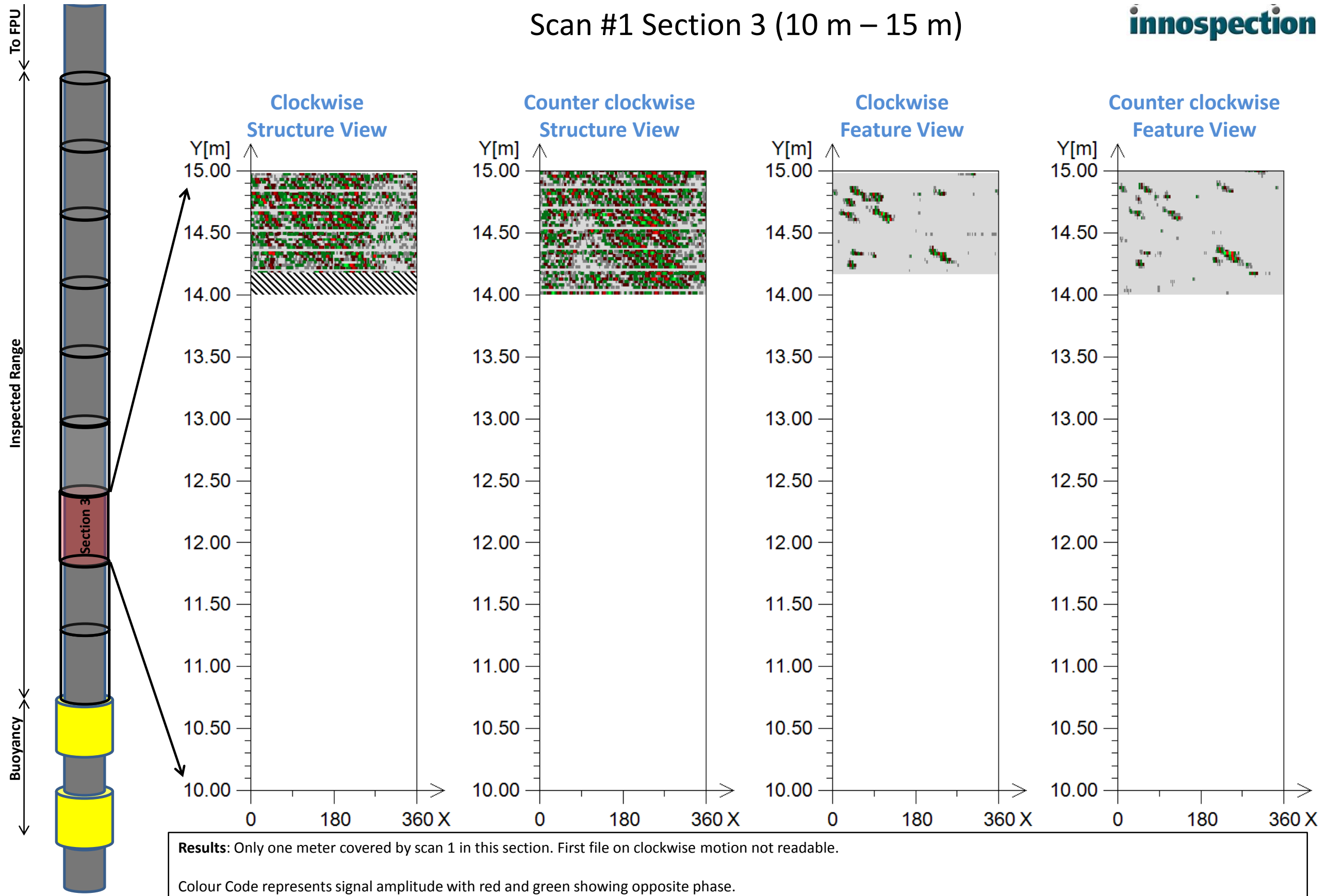
Scan #2 Section 2 (5 m – 10 m)



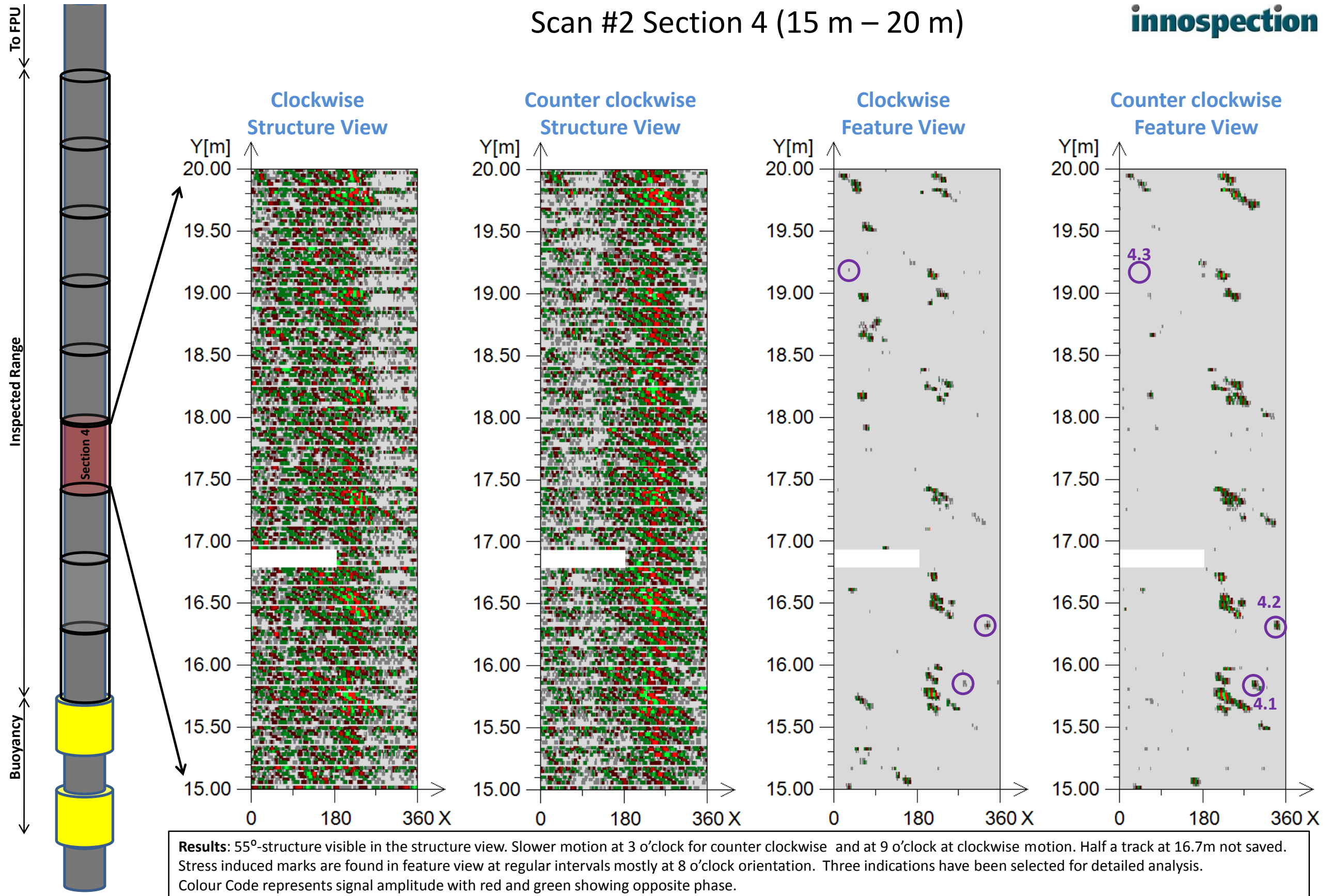
Scan #2 Section 3 (10 m – 15 m)



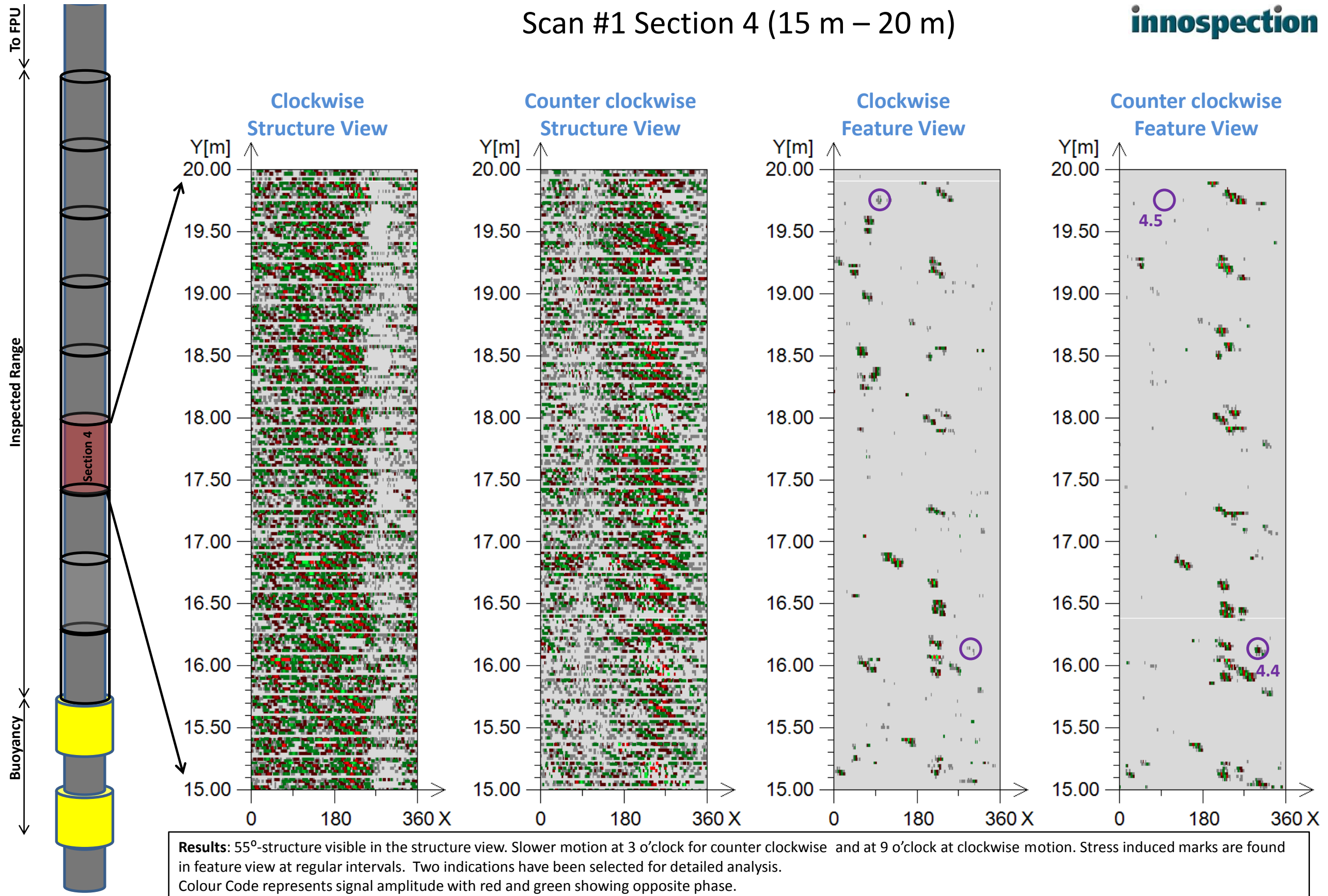
Scan #1 Section 3 (10 m – 15 m)



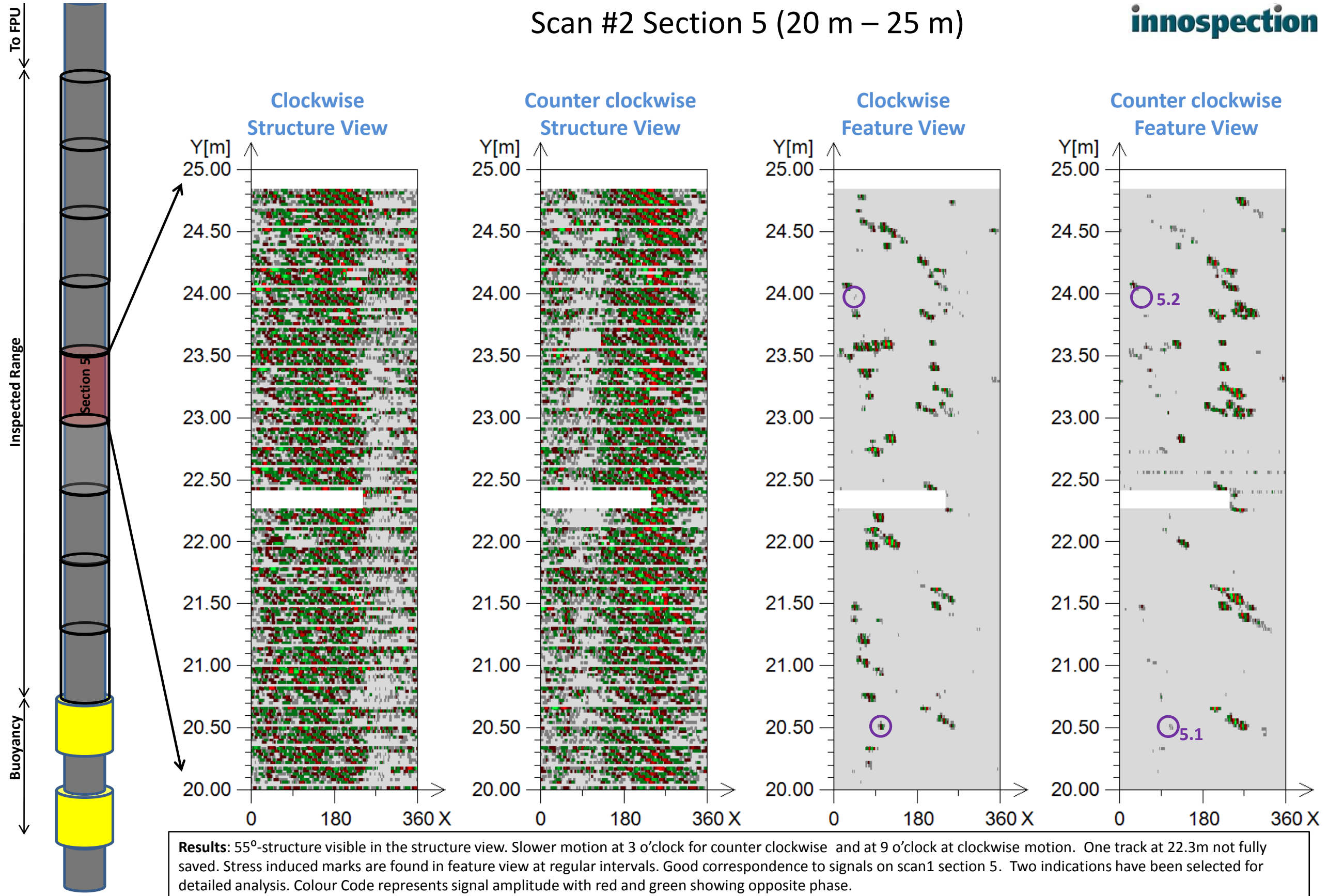
Scan #2 Section 4 (15 m – 20 m)



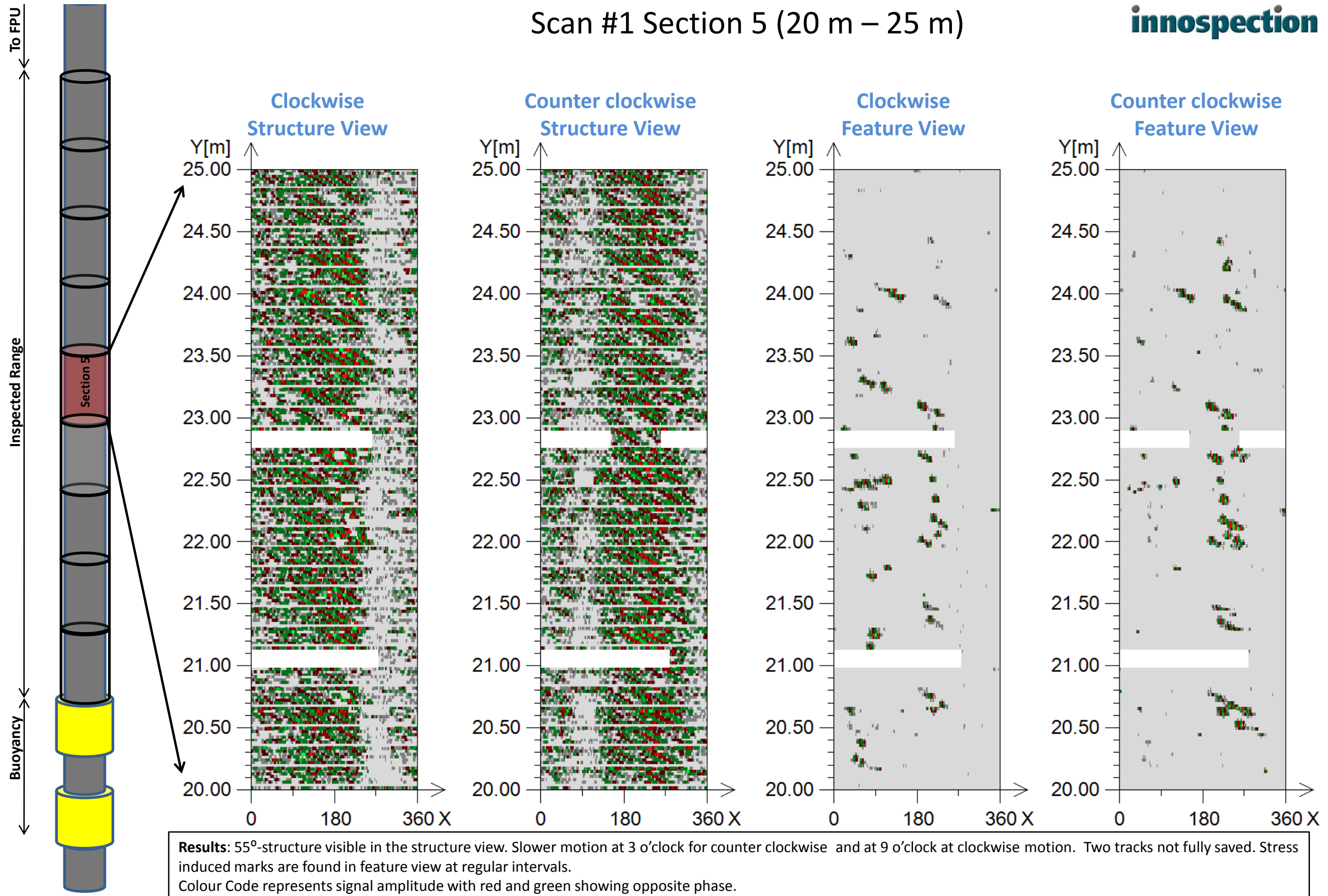
Scan #1 Section 4 (15 m – 20 m)



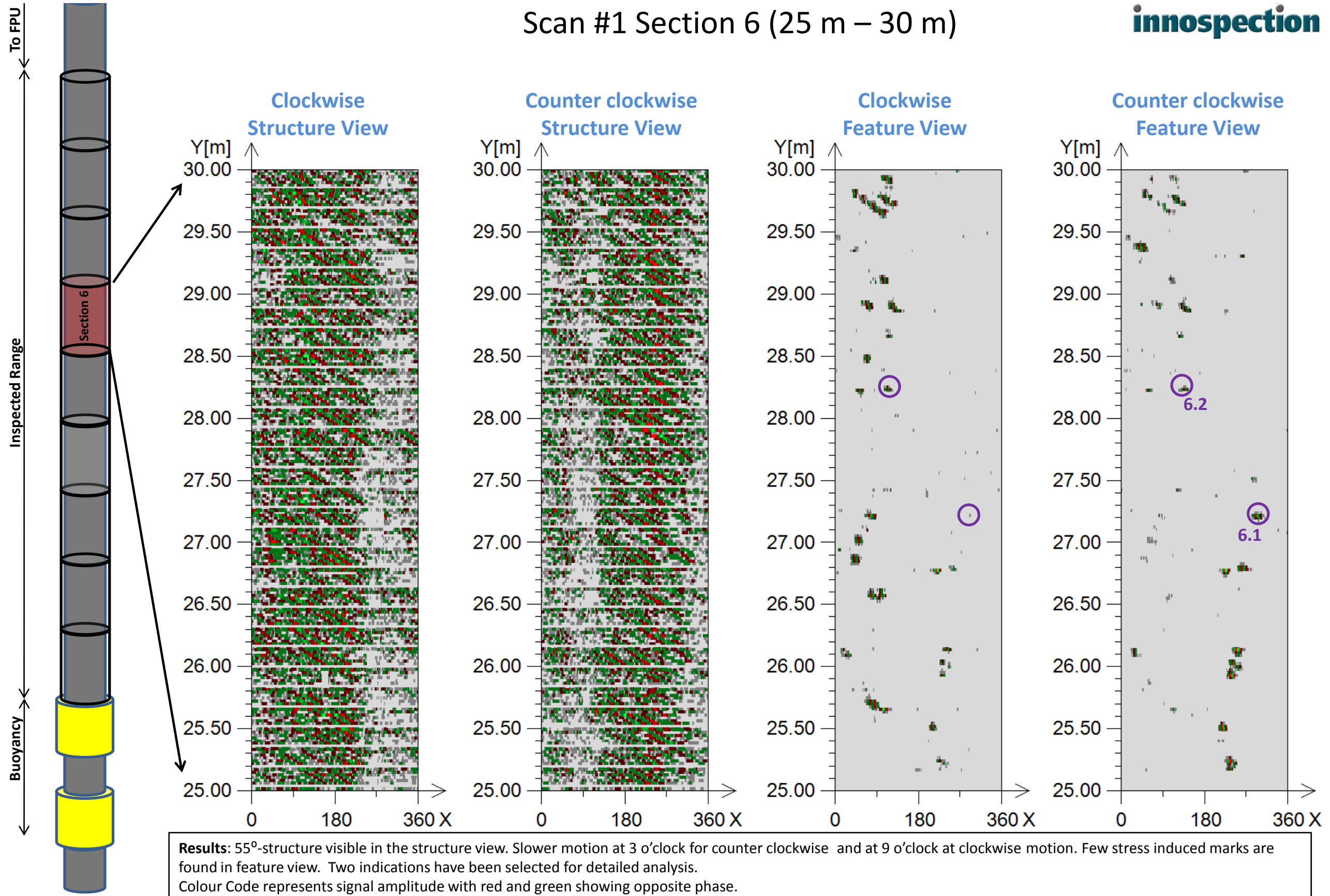
Scan #2 Section 5 (20 m – 25 m)



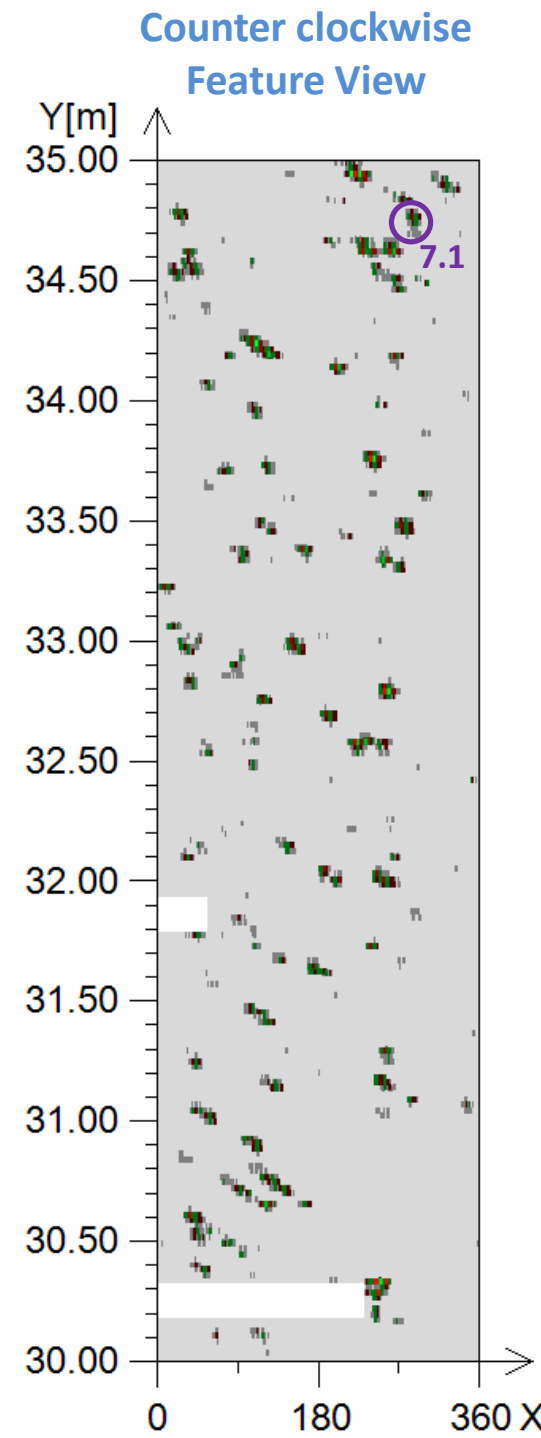
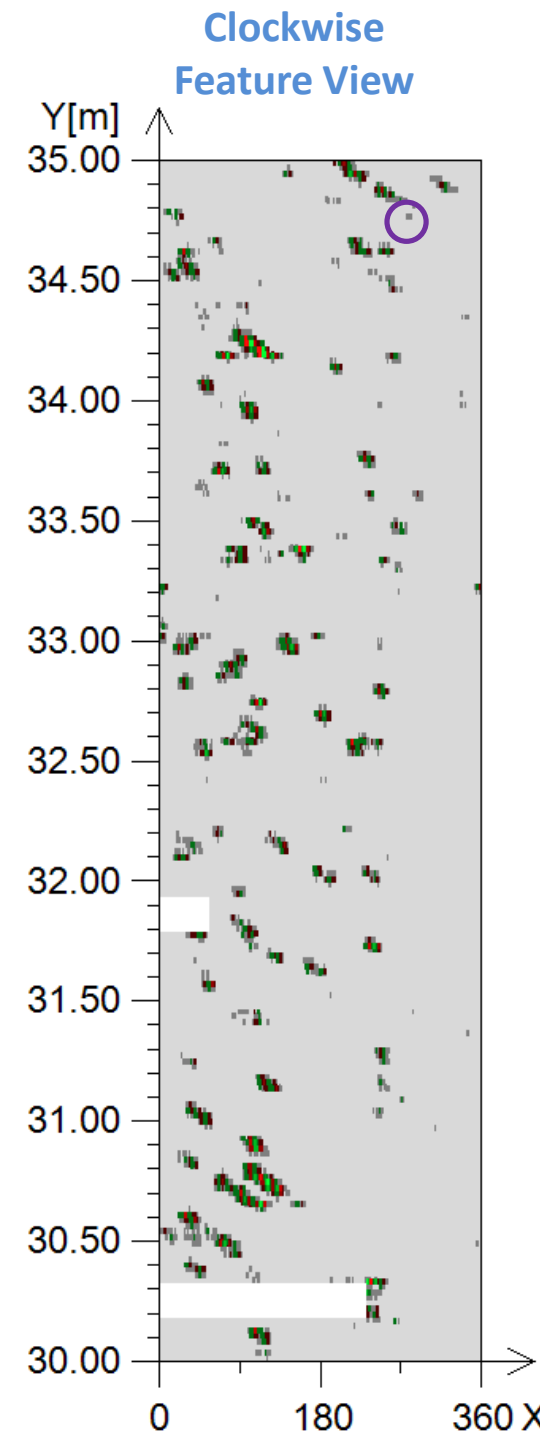
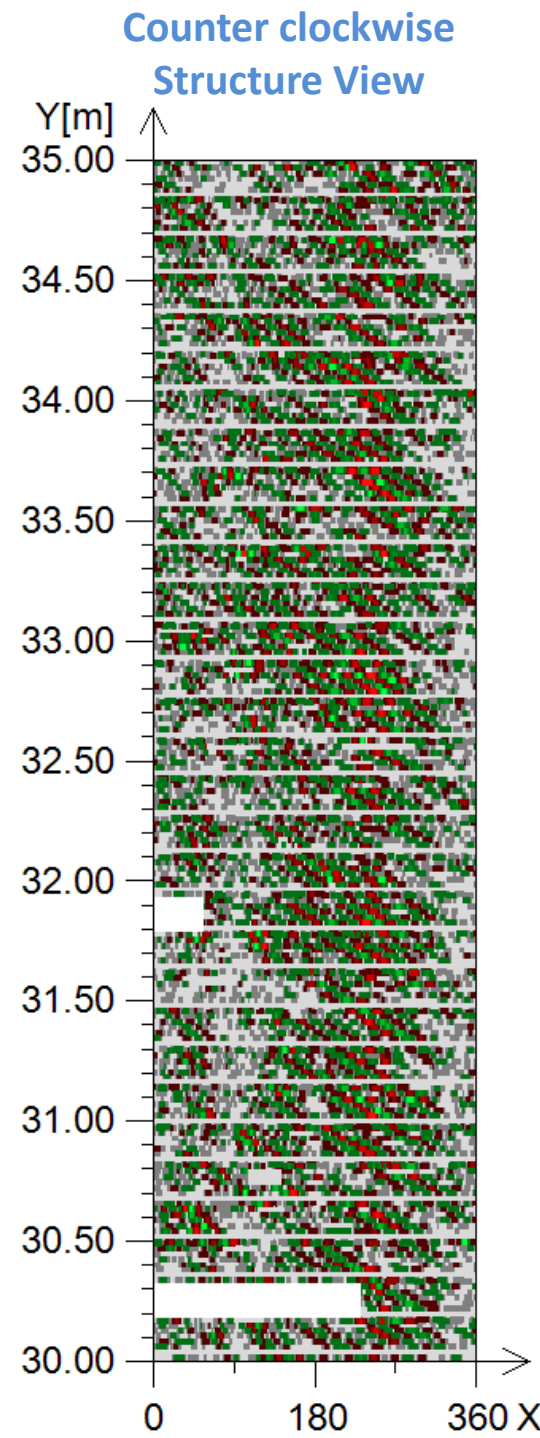
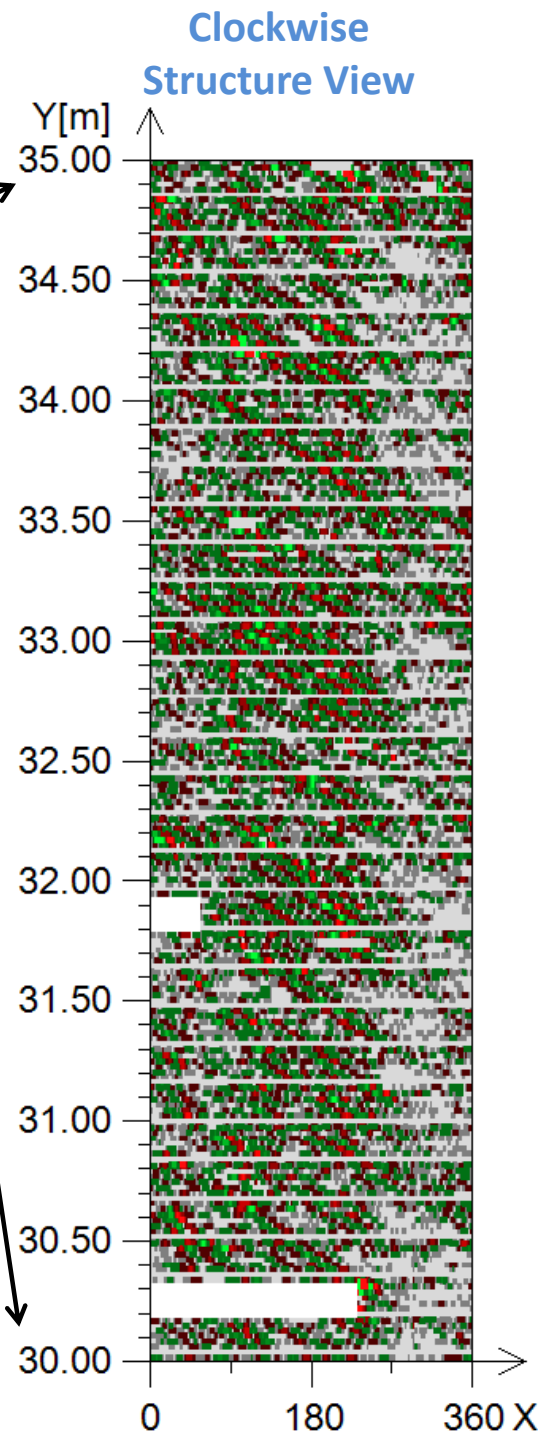
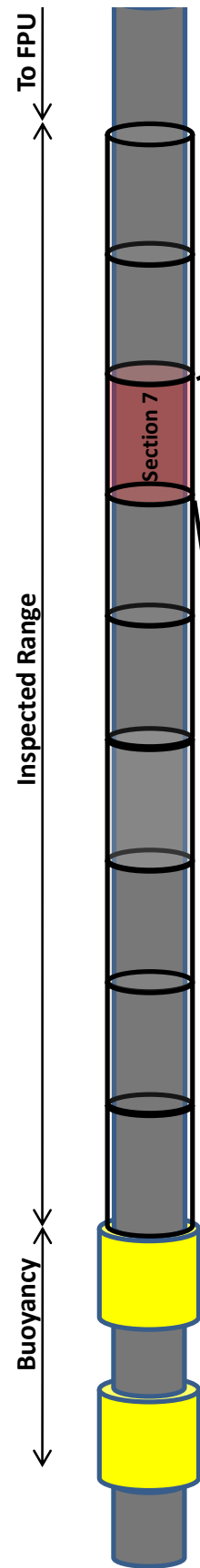
Scan #1 Section 5 (20 m – 25 m)



Scan #1 Section 6 (25 m – 30 m)

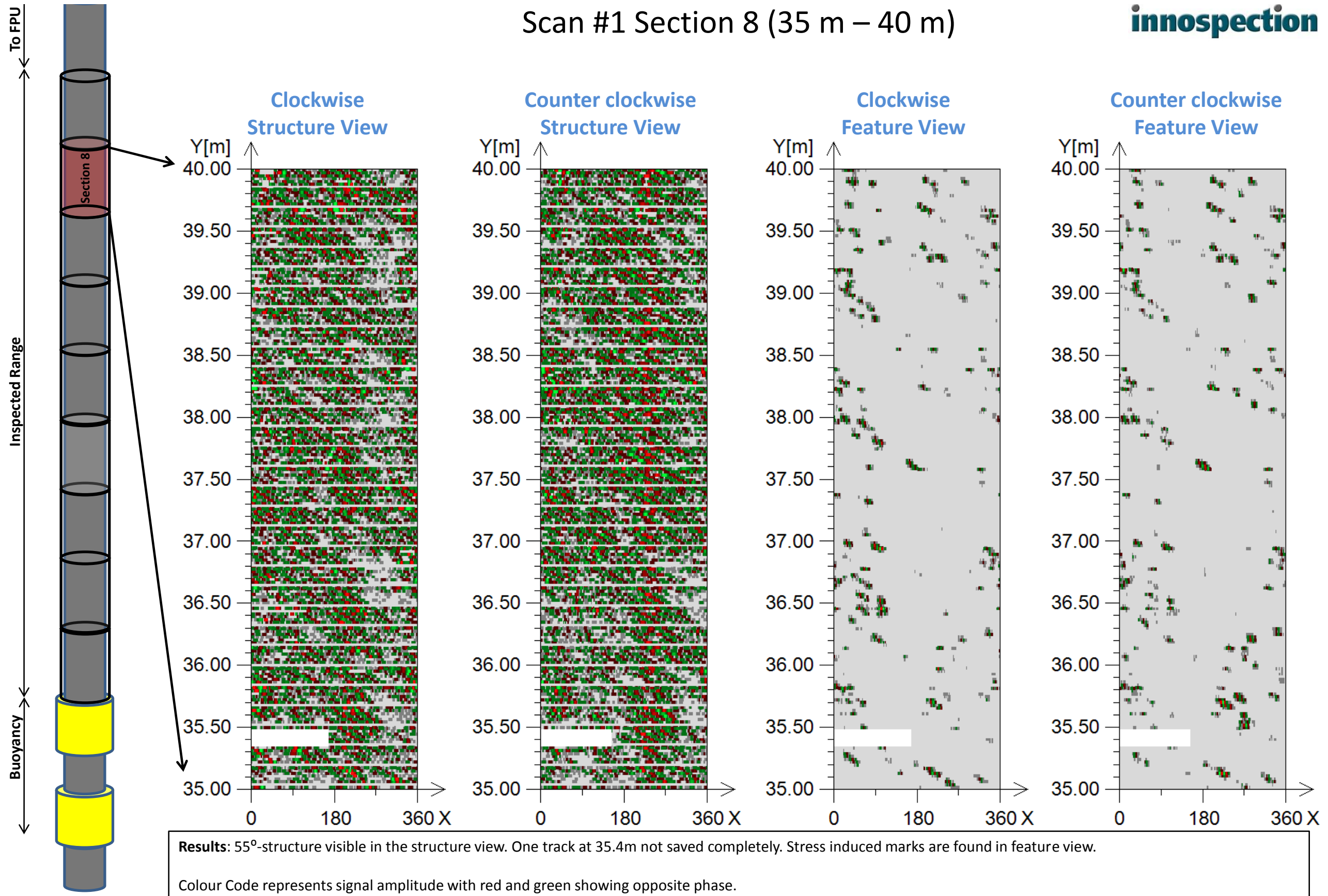


Scan #1 Section 7 (30 m – 35 m)

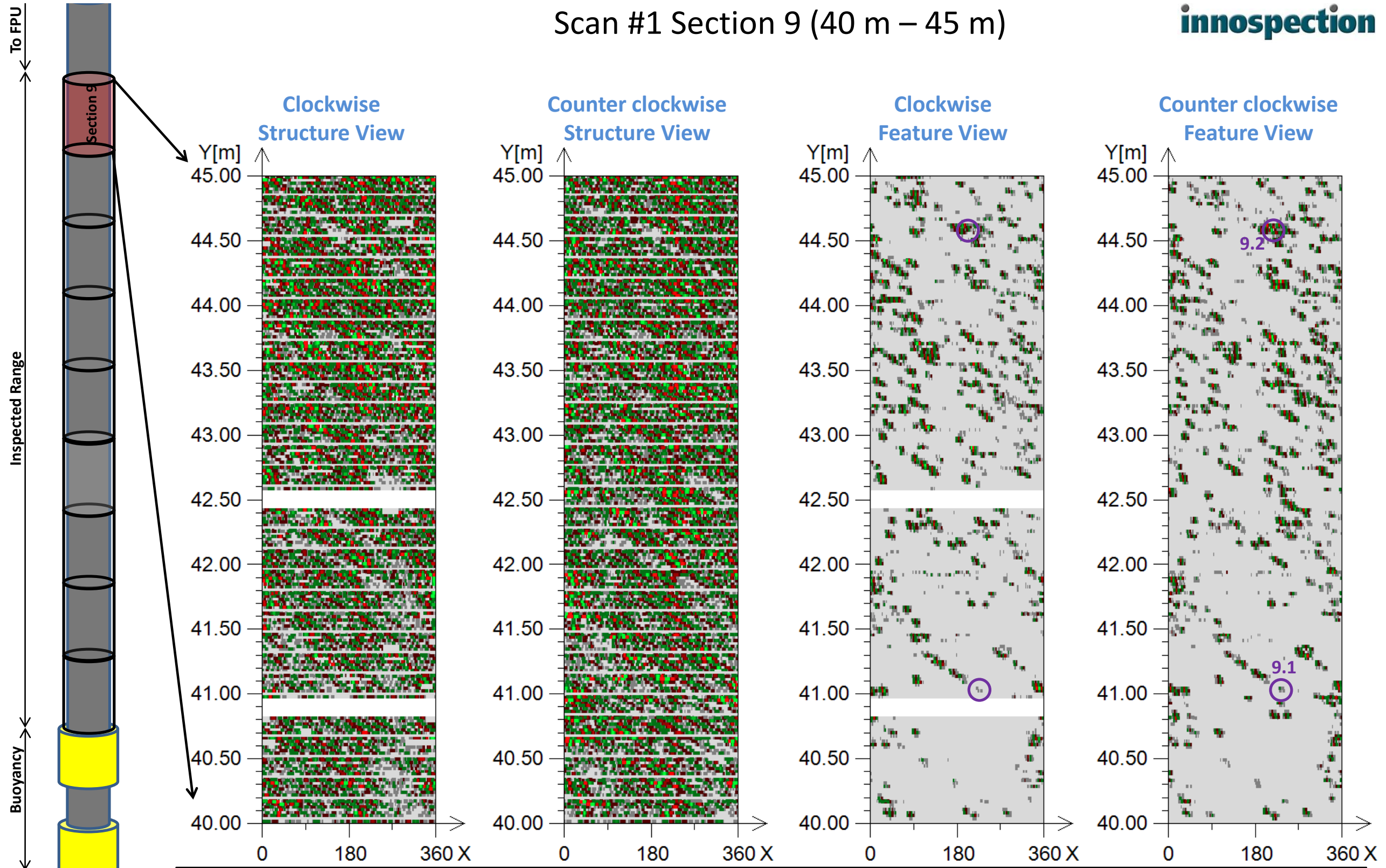


Results: 55°-structure visible in the structure view. Slower motion at 3 o'clock for counter clockwise motion. Two portions of track missing. Stress induced marks are found in feature view. One indication has been selected for detailed analysis.
Colour Code represents signal amplitude with red and green showing opposite phase.


Scan #1 Section 8 (35 m – 40 m)



Scan #1 Section 9 (40 m – 45 m)



Results: 55°-structure visible in the structure view. One tracks on clockwise motion not saved. Stress induced marks are found in feature view especially dense towards the end of the scan. Two indications have been selected for detailed analysis. Colour Code represents signal amplitude with red and green showing opposite phase.

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3.2. Findings

In the structure view a regular pattern of 55° wires is visible. As anticipated the data quality is degraded near the slow motion or interruption at 9 o'clock for the clockwise scan and 3 o'clock for the counter clockwise motion. Both images in combination yield the full picture.

In the features view there is an abundance of indications. They are more pronounced in the start and the end of the scan. In the sag bend the density of these features is smaller. As these features can be exactly reproduced between clockwise and counter clockwise movement and also between the two scans for the overlapping sections they definitely stem from the armour wire layers. They tend to show an anisotropy comparable to the outer wire structure. In section 4 the pattern is less dense. Here the spots are exactly 0.85 m apart. This happens to be the pitch of one wire at full circumference. Hence the same wire is affected at the same orientation. Refer to Figure 6 for a sample signal of this kind.

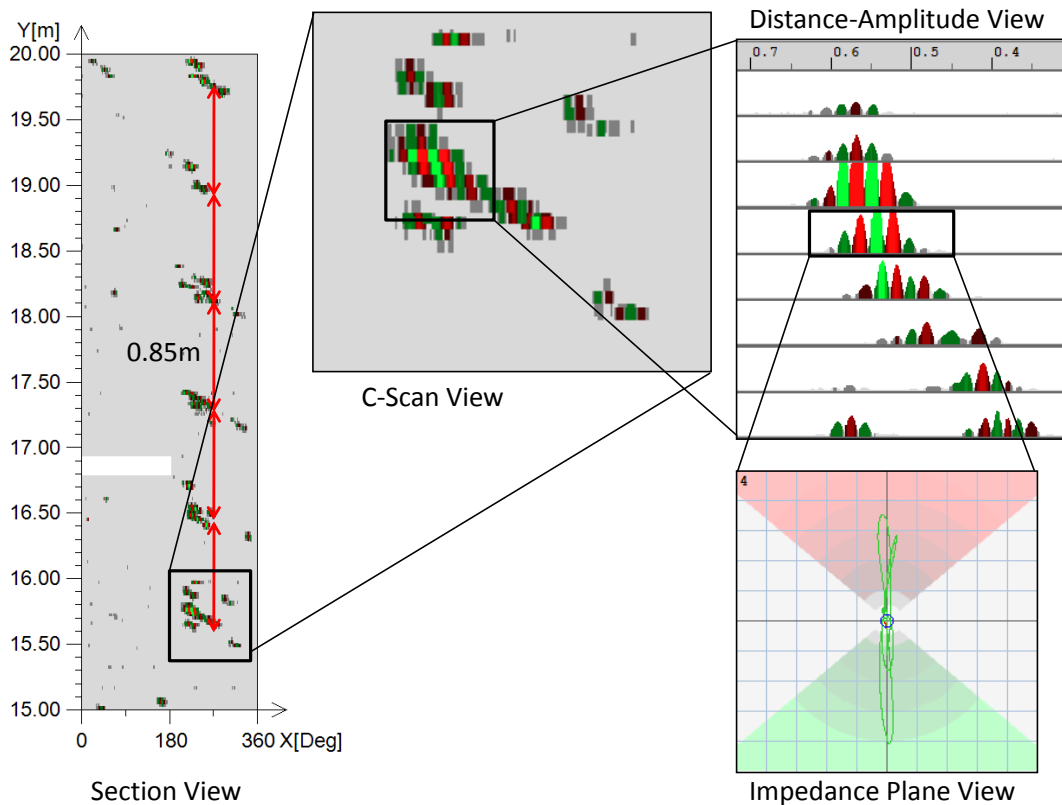


Figure 6: A sample Data section with different views. Data is taken from Section 4 Scan2 counter clockwise motion.

From their appearance the signals are attributed to residual stresses (see 3.3).

All of the data was investigated to possible relevant signals embedded in the above described features. Relevant signals such as crack-like signals do not necessarily extend over a large area. Hence, all smaller features of interest are identified.

They are encircled in the features view. They are numbered with the section-No. first and then continuously by distance. The table below gives an overview of all of these features. It had to be investigated, if these features are true cracks or only show a certain similarity to cracks and are really of different origin.


Item No.	Distance [m]	Orientation [deg]	Description
1.1	0.15	350	
1.2	0.75	305	
1.3	1.25	180	
1.4	4.20	90	
1.5	4.75	315	
2.1	6.85	50	
2.2	7.45	55	
3.1	11.20	255	
3.2	11.85	10	
3.3	12.65	360	
3.4	14.55	330	
4.1	15.85	280	corresp. 4.4
4.2	16.36	340	
4.3	19.06	40	
4.4	16.10	285	corresp. 4.1
4.5	19.80	90	corresp. 5.1
5.1	20.50	100	corresp. 4.5
5.2	23.95	50	
6.1	27.18	290	
6.2	28.25	120	
7.1	34.75	300	
9.1	41.00	260	
9.2	44.58	220	

Table 4: table of features that were investigated for possible cracks

A closer investigation has shown that these features are also related to stresses and possible material plastification. They are smaller in size and are more isolated as compared to the larger features.


3.3. Conclusion

A pattern of signals is found throughout the inspected area. Based on the signal behaviour in the impedance plane view and the fact that they mostly follow the outer wire structure it can be concluded that they are of stress related origin. The MEC™ method is also sensitive to

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residual stressed in wires. The fact that in some cases the same wire is affected only separated by one full winding, allows concluding that the cause is mostly manufacturing related. To what degree the indications can grow through operational conditions cannot be said.

All signals have been investigated with respect to possible crack-like features embedded in them. In the end none of these extra smaller indications have been classified as cracks.

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4. Technical Details of the Instrumentation

4.1. Description of the MEC™-FIT Technology

Standard eddy current instrumentation is only sensitive to the surface of an electromagnetic material. Even this can be quite a benefit for the inspection of flexible riser pipe. However, modifications of the standard eddy current technologies allow for the inspection of deeper structures. The Innospection magnetic biased eddy current solution has been found to be a versatile method for the inspection of ferritic steel structures. The principle technique is known as Saturation Low Frequency Eddy Current. The principle technique has been extended, modified and adapted for flexible riser inspection and is now known as MEC™-FIT.

The idea of MEC™-FIT is to use an eddy current coil on ferromagnetic material and to magnetise the section of ferritic steel components at the same time. The magnetisation has several effects. It changes the permeability of the material. Hence, the penetration depth increases. At the same time changes in permeability due to different flux distribution become visible. With these effects also defects embedded in the material can be picked-up with eddy current sensors. The principle is shown in Figure 7.

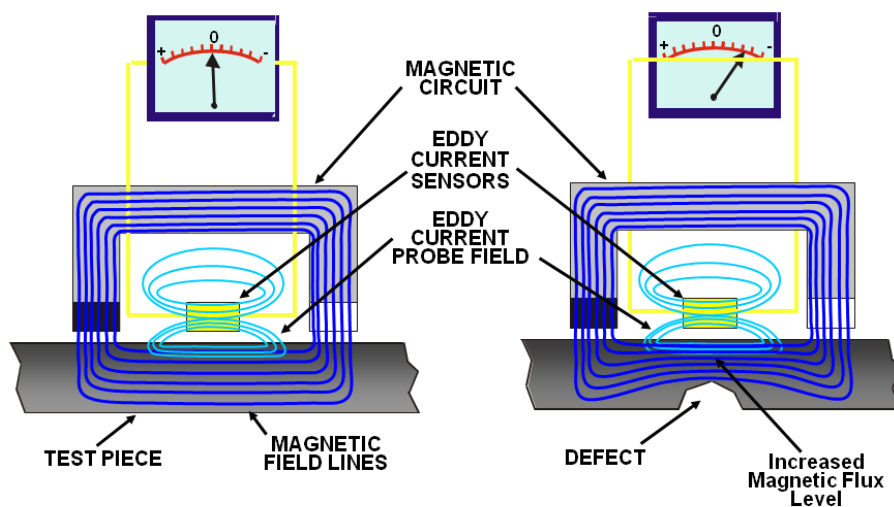



Figure 7: Depiction of the magnetically biased eddy current principle MEC™-FIT.

The principle of the technique is that a DC magnetisation of the ferromagnetic material is changing its magnitude in case of material changes such as defects. This change affects the eddy current field which is applied between the DC magnetic poles. The change of the eddy current field is reflected to the impedance of the eddy current sensor. The indication of the impedance change of the sensor is used to analyse the type and severity of the material changes. The impedance change of the MEC™-FIT eddy current type sensor allows analysing its phase, its amplitude and signal pattern. This provides details of the defect in

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size, criticality and in combination with the DC magnetic field analysis giving details from which layer the indication (defect) reflects from.

The principle of measurement is to some extent related to MFL-measurement, but the set-up works at lower magnetisation levels. Since only moderate levels of magnetisation are required, the method works to higher wall thickness pipe, or through several millimetres of coating thickness.

One of the most defining aspects of flexible riser pipe is the presence of wires or strings running helically around the pipe. This has a fundamental impact on electromagnetic NDE methods and also MEC™-FIT. The question of the scanning and magnetisation direction needs to be considered. Several configurations can be conceived. The magnetisation mainly runs along the wires. Hence, the orientation of the wires has an influence on the magnetisation state in particular on the edges. Figure 8 shows the change in the magnetisation condition for a wire structure of 35° (left) versus a wire structure of 15° (right). Some non-uniformities on the edges present in the 35°-structure are not present in the 15° structure.

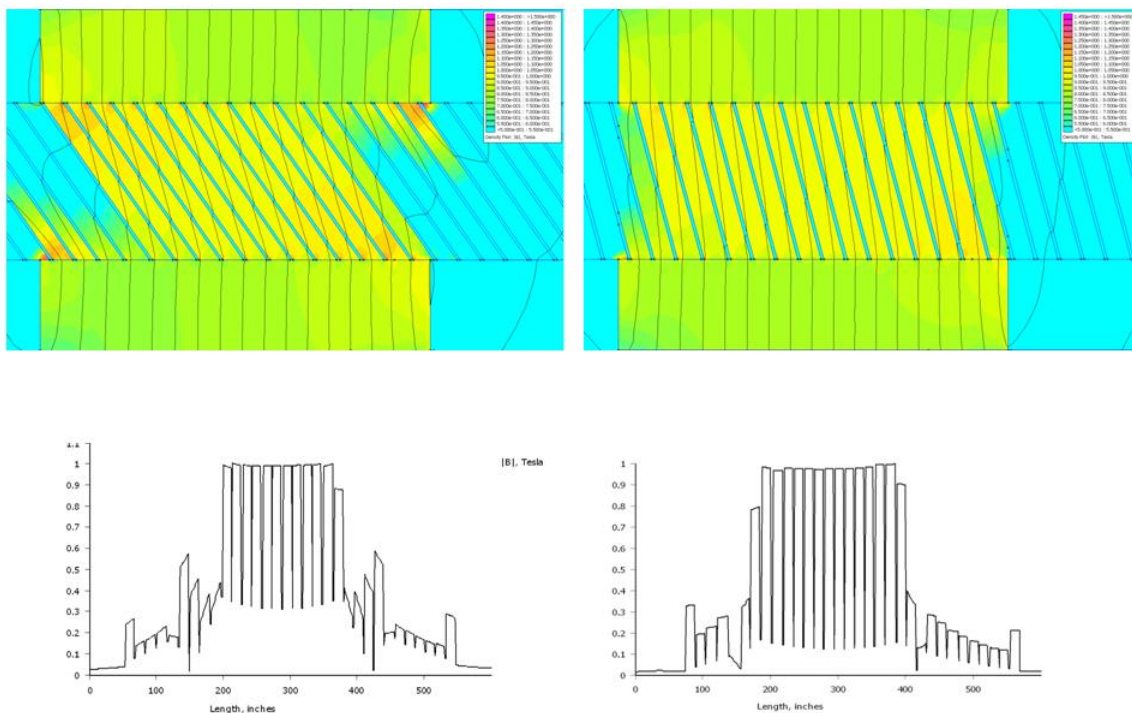



Figure 8: Change of magnetisation condition with angle of armour wires (35° structure depicted on the left, 15° structure on the right). Upper part: Level of magnetisation in colour code. Lower part: Magnetisation level in wires.

When running axially on a pipe with a 55°-structure, it is difficult to magnetise the wires properly. In addition the natural gaps between the wires will generate a large signal background. For the inspection of 55°-structures the scanning orientation is thus turned from

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axial to circumferential. With respect for the wire orientation the conditions are then the same as for axial scanning.

For mechanical reasons only axial and circumferential scanning is reasonable. In most cases MEC™-FIT uses differential sensors to inspect the specimen. A differential sensor basically consists of two coils and the difference between the two is measured. This makes the probe especially sensitive to abrupt changes in the material. For corrosion or crack-like defects this is the sensor of choice. It would be rather insensitive for gradual changes in the material like wall thickness erosion. An absolute sensor can be used for this purpose.

The signal itself is represented in an impedance plane. For differential sensors it basically consists of loops. These loops run in different directions, called a phase. The analysis of the phase allows conclusions on the nature and origin of the signal. A filter allows for selecting signals that run in a predefined direction or phase angle. A sample signal is shown in Figure 9. In this case the signal falls within the selected phase sector and the amplitude is displayed in the colour code shown. Signals with a phase outside of the selected sector are discriminated. If this is done for all sensors C-Scan-like bitmap can be generated for every scan (track). For the inspection of flexible riser the colour code shown on the right is used. Here the two opposite phases are distinguished. A distance encoder allows for the measurement of the scanned distance. The bitmaps thus show the signal is a defined pixel/per mm relation. Tracks of adjacent scans are merged to one complete picture of the scanned area.

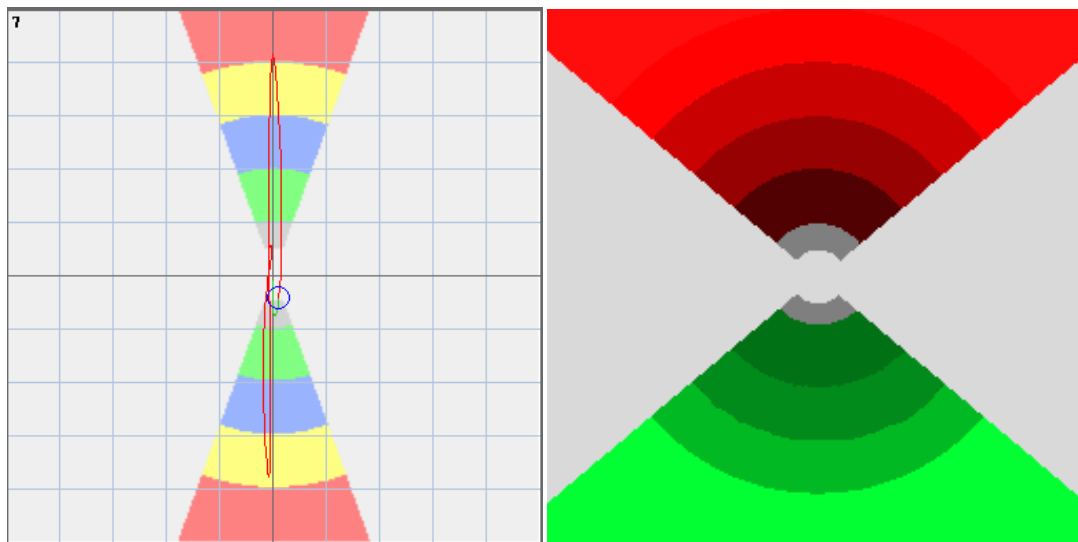



Figure 9: Left: The loop of a differential sensor with the selected phase angle in colour code shown in the background. Right: Colour Code used for flexible riser inspection.

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4.2. Description of the MEC™- Pipe Crawler Tool

The MEC™- Pipe Crawler tool employs the proven MEC™-FIT (**M**agnetic **E**ddy **C**urrent) inspection technology (a further development of the Saturation Low Frequency Eddy Current) in a tool for subsea deployment. It allows for scanning in the circumferential direction of the pipe and can be positioned at any axial orientation using the hydraulically driven wheels of the tool. The scanner head with a multiple sensor array covers 180 mm axially. The tool is advanced by a distance smaller than the scanning width to ensure an appropriate overlap. The tool is shown in Figure 10.

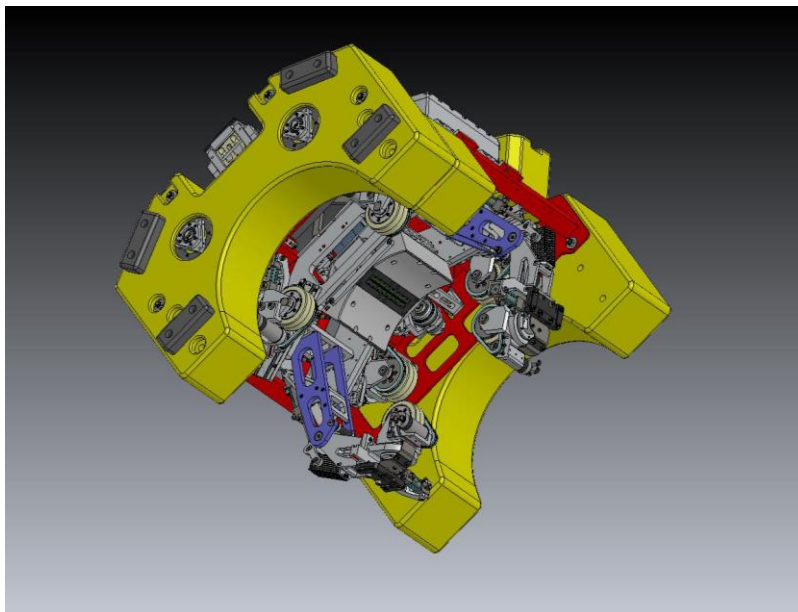


Figure 10: The MEC™-Pipe Crawler tool for the inspection of pipes with top-side deployment (bottom view)

The distances driven are measured with an encoder-wheel. The encoder wheel and the drive wheels turn by 90° in order to change between axial and circumferential scanning. An umbilical is connected to the tool for supply of electrical and hydraulic power and for routing of the signals to a top-side eddy current data-acquisition system. The magnetisation level is controlled hydraulically.