Investigation into a Microbiologically Induced Corrosion (MIC) failure of an onshore pipeline

Keith Birkitt CEng MWeldI FIMMM, Principal Materials Engineer
Aneta Nemcova PhD MIMMM, Materials Scientist
Ian Chapman CEng MIMechE, Mechanical Engineering Inspector

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Introduction

- Pipeline Degradation Mechanisms
- Microbiological Induced Corrosion
- Detecting MIC
- Onshore MIC Incident
- In-Service Monitoring

Pipeline Degradation Mechanisms:

External:

- Atmospheric corrosion, especially in coastal and industrial locations
- Crevice corrosion, e.g. under pipe supports
- Galvanic corrosion
- Stress Corrosion Cracking (SCC)
- Corrosion under insulation (CUI)
- Microbiological Induced Corrosion (MIC)

Pipeline Degradation Mechanisms:

Internal:

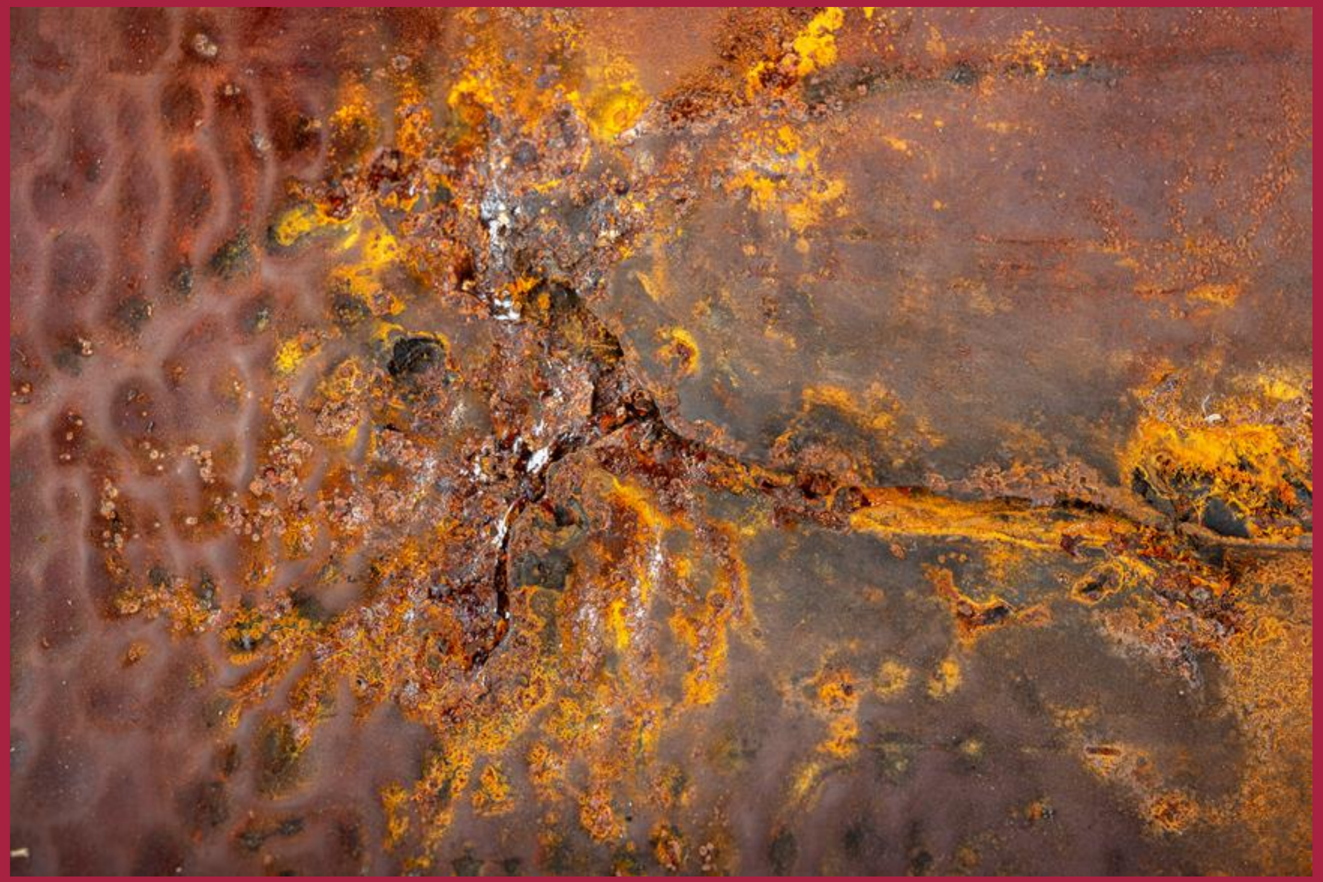
Erosion-corrosion/cavitation

Galvanic corrosion

CO_2 corrosion

Stress Corrosion Cracking (SCC)

Microbiological Induced Corrosion (MIC)



Understanding the mechanisms appropriate to the operating conditions is an important part of the asset management programme.

Microbiological Induced Corrosion (MIC)

- Caused by living organisms: bacteria, algae, fungi
- Occurs in low flow or stagnant environments
- Fast flow tends to flush away the offending species
- MIC caused by a variety of organisms under severe conditions of light/dark, high salinity, low to moderately high pH, and temperatures ranging from -17 ˚C to +113 ˚C
- Different organisms thrive on different nutrients e.g. sulphur, ammonia, H_2S, hydrocarbons and organic acids
- Require a source of carbon, nitrogen and phosphorous for growth
- Can be found in heat exchangers, bottom of storage tanks, stagnant/low flow pipework and pipework in contact with soils

Mechanism of MIC

- Micro-organisms create acids as a by-product of their existence
- Sulphate reducing bacteria (SRB) are responsible for the majority of failures and live in oxygen-free environments
- Often characterised by deep pits, e.g. carbon steel pipelines

Detection

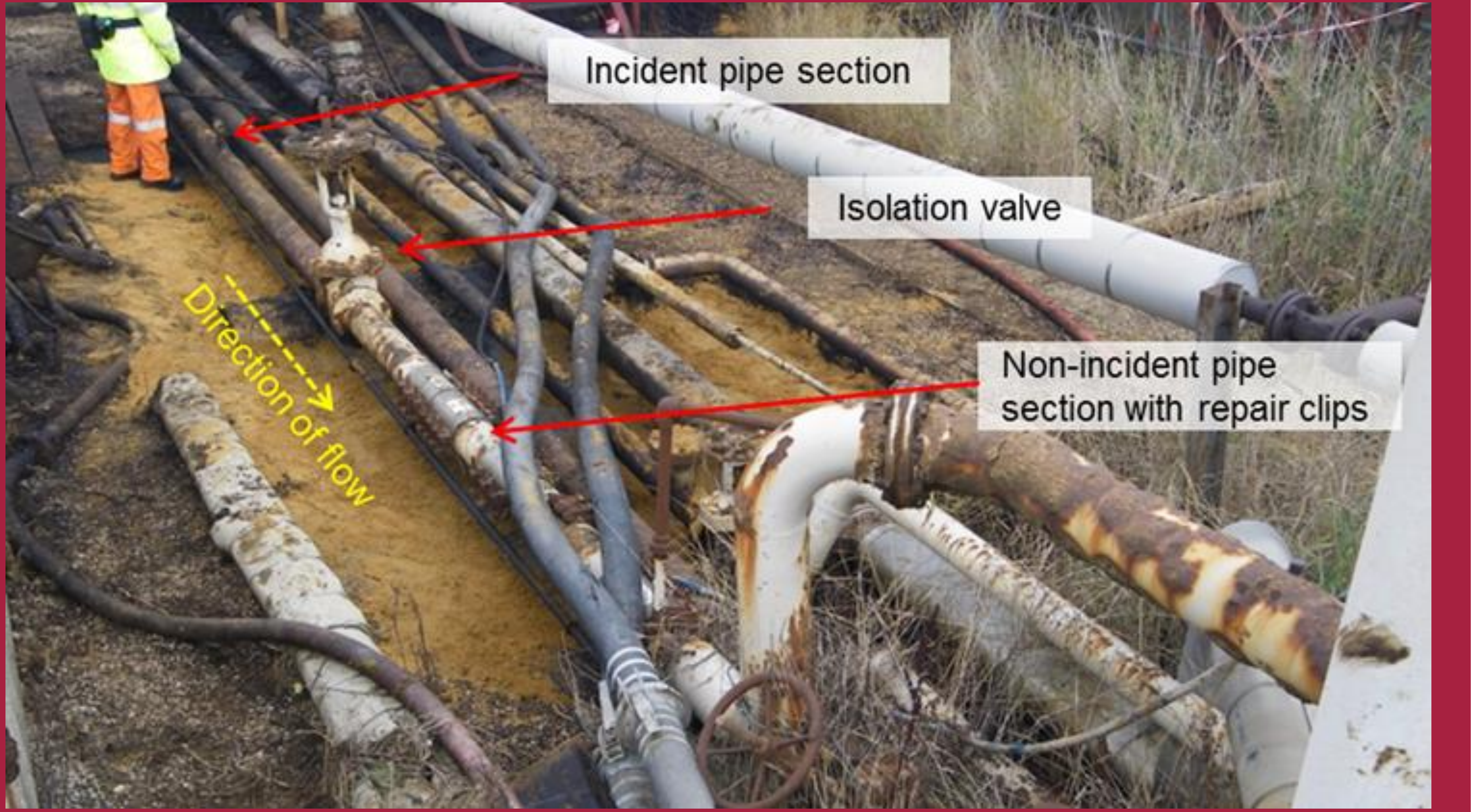
Various methods:

- Culture-based testing
- Optical microscopy, such as DAPI (4-6-diamidino-20phenylindole)
- FISH (Fluoresce in situ hybridisation)
- DNA analysis such as qPCR (Quantitative Polymerase Chain Reaction)
- ATP (Adenosine Triphosphate Photometry)

NACE document TM0212-2018

Onshore Incident

- Loss of containment of 450 m^3 liquid hydrocarbon and water mixture
- 6 inch (150 mm) diameter pipeline
- Pipework normally dormant, however temporary re-routing of pipe flow required



Methodology

Two sections of pipe retrieved:

- Incident – the section which leaked
- Non-incident – an adjacent length of pipe with multiple repair clamps

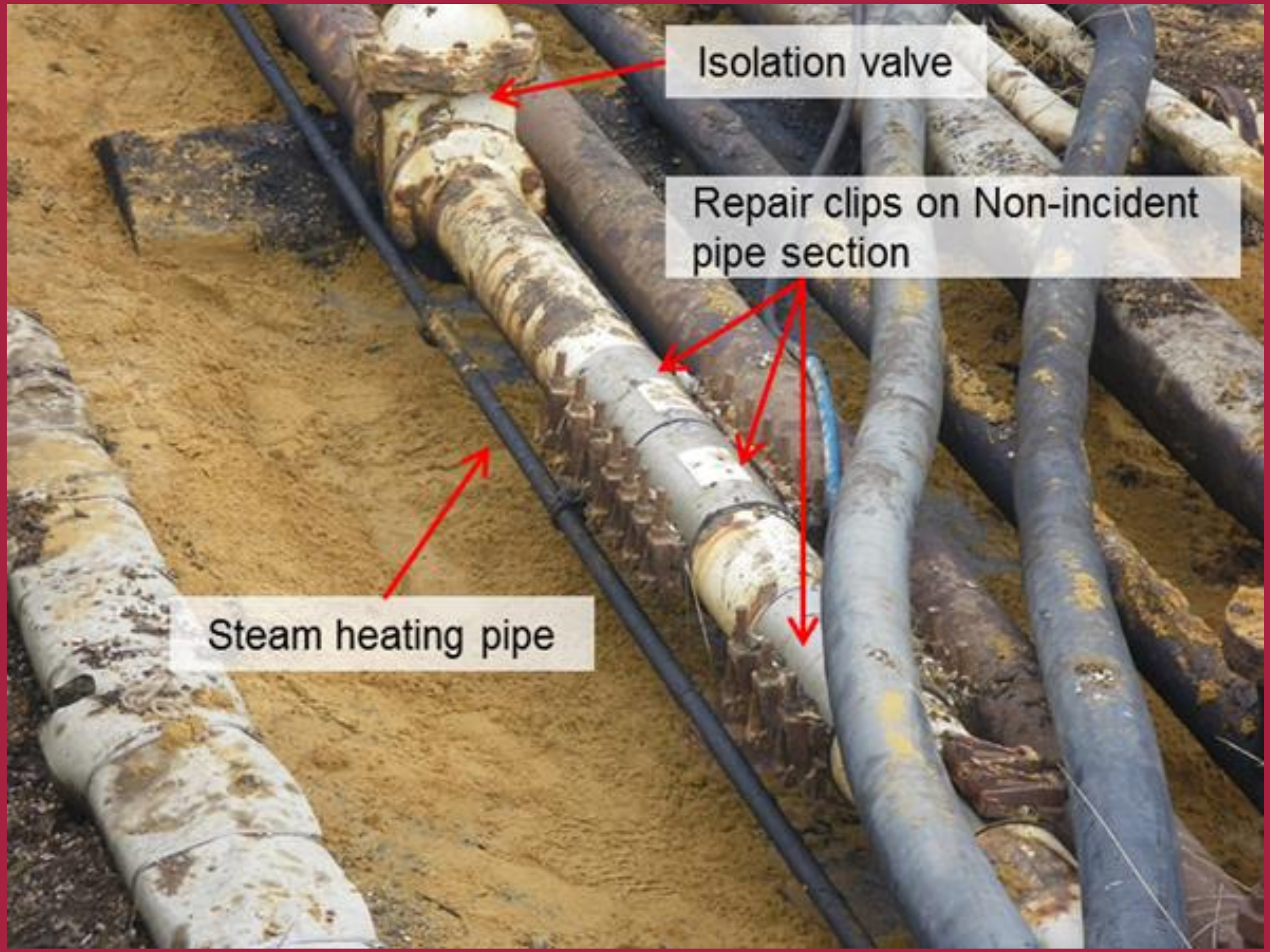
Decontamination on site
Visual examination
Material analysis: ICP OES of pipe material
XRD of solid pipe contents
Metallography
Hardness testing
Laser scanning to measure wall thickness and identify wall thinning
Micro-biological analysis by qPCR to determine:

- Total (live and dead) bacteria
- Presence of SRB (sulphate reducing bacteria)
- Presence of SRA (sulphate reducing archaea)

Results and Discussion

Visual examination

- Evidence of a steam heating pipe
- Six repair clips
- Wall thickness 5mm in non-corroded areas (originally 7 mm)
- Evidence of previous painting
- External corrosion and spalling
- Perforations at 6 o’clock position

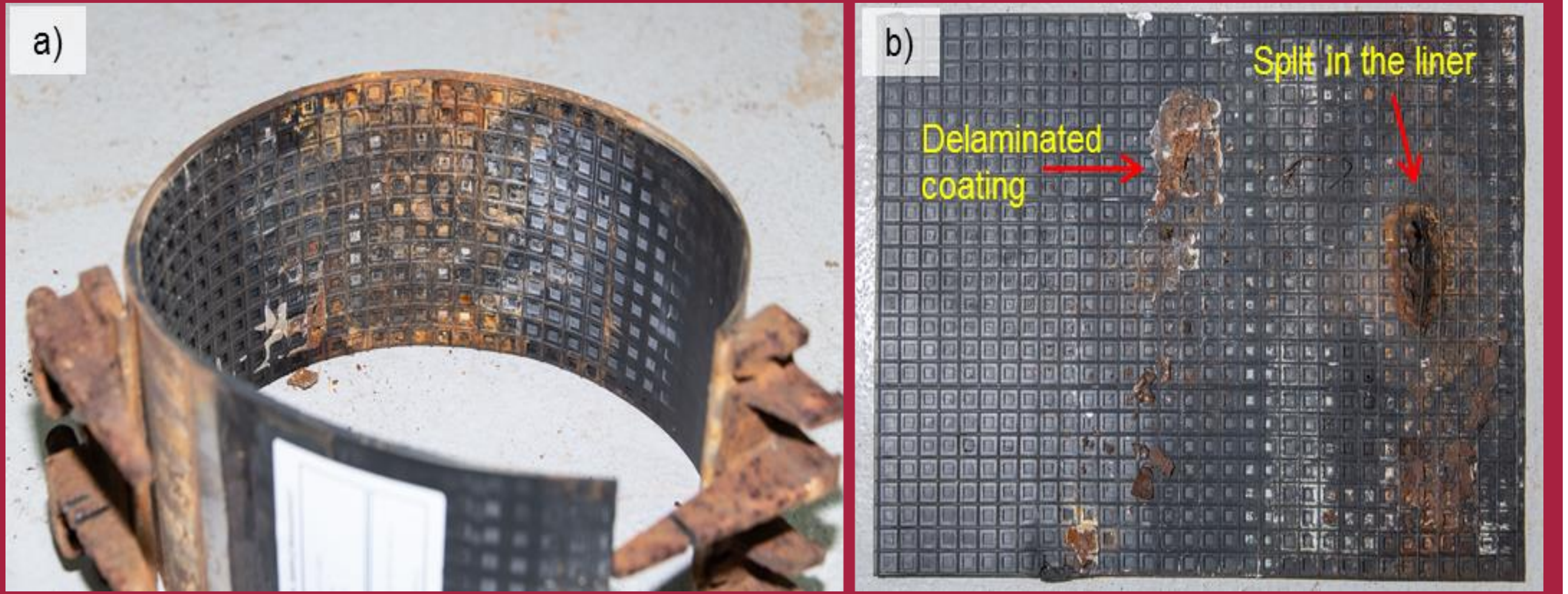


Visual examination

a. Paint on non-incident pipe
b. Incident pipe external corrosion
c. Drain on non-incident pipe
d. Defect associated with loss of containment

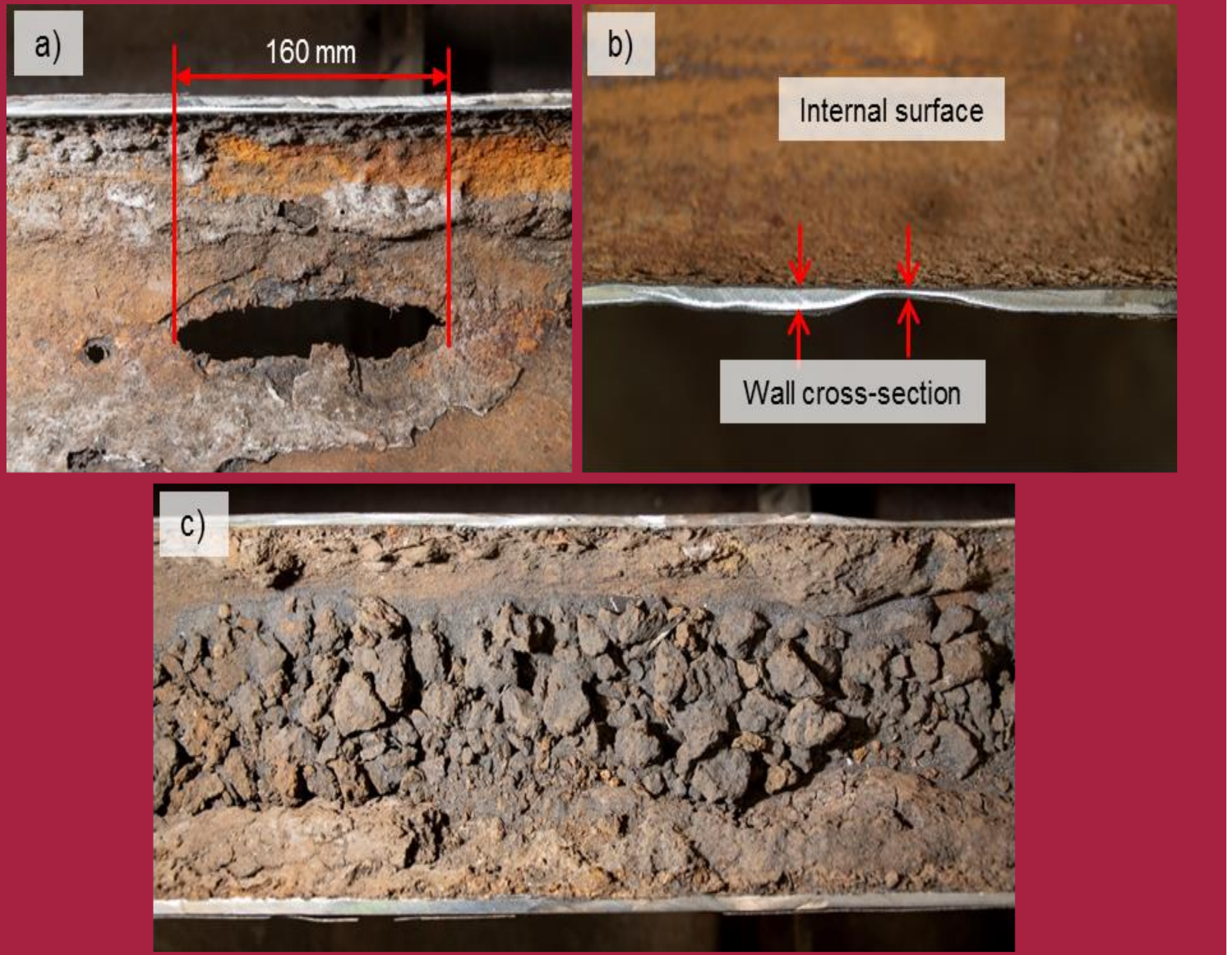
- Defects under the clips were close to joining up

Liner condition



Internal examination

- Pipes cut longitudinally at 3 and 9 o'clock position:
- Significant internal deposit of solid debris and corrosion product
- Internal and external corrosion evident



Materials analysis

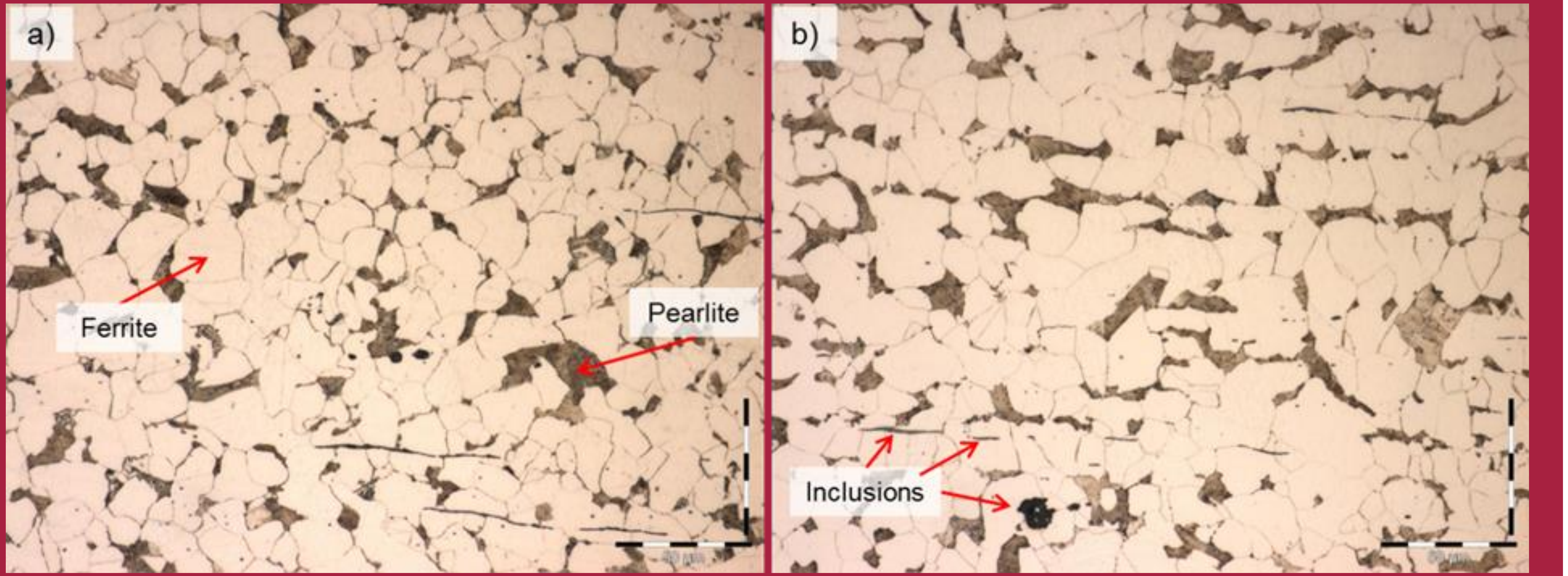
- ICP OES revealed analysis consistent with API 5L grade B steel
- XRD of deposits revealed SiO_2 (silica) and $FeCO_3$ (siderite) – i.e. sand and corrosion products of iron

Element	Incident pipe	Non-incident pipe	API 5L grade B
Carbon	0.16	0.14	Max.0.26
Silicon	0.19	0.17	-
Manganese	0.60	0.68	Max.1.15
Phosphorous	0.017	0.021	Max. 0.04
Sulphur	0.029	0.035	Max. 0.05
Chromium	0.05	0.04	-
Copper	0.23	0.15	-

Metallography

- Ferrite/pearlite microstructure consistent with the chemical analysis
- Hardness of 136 HV10 (incident pipe) and 130 HV10 (non incident pipe)
- Equivalent ultimate tensile strengths (UTS) of 430 MPa and

  415 MPa
- Metallography and UTS consistent with API 5L grade B

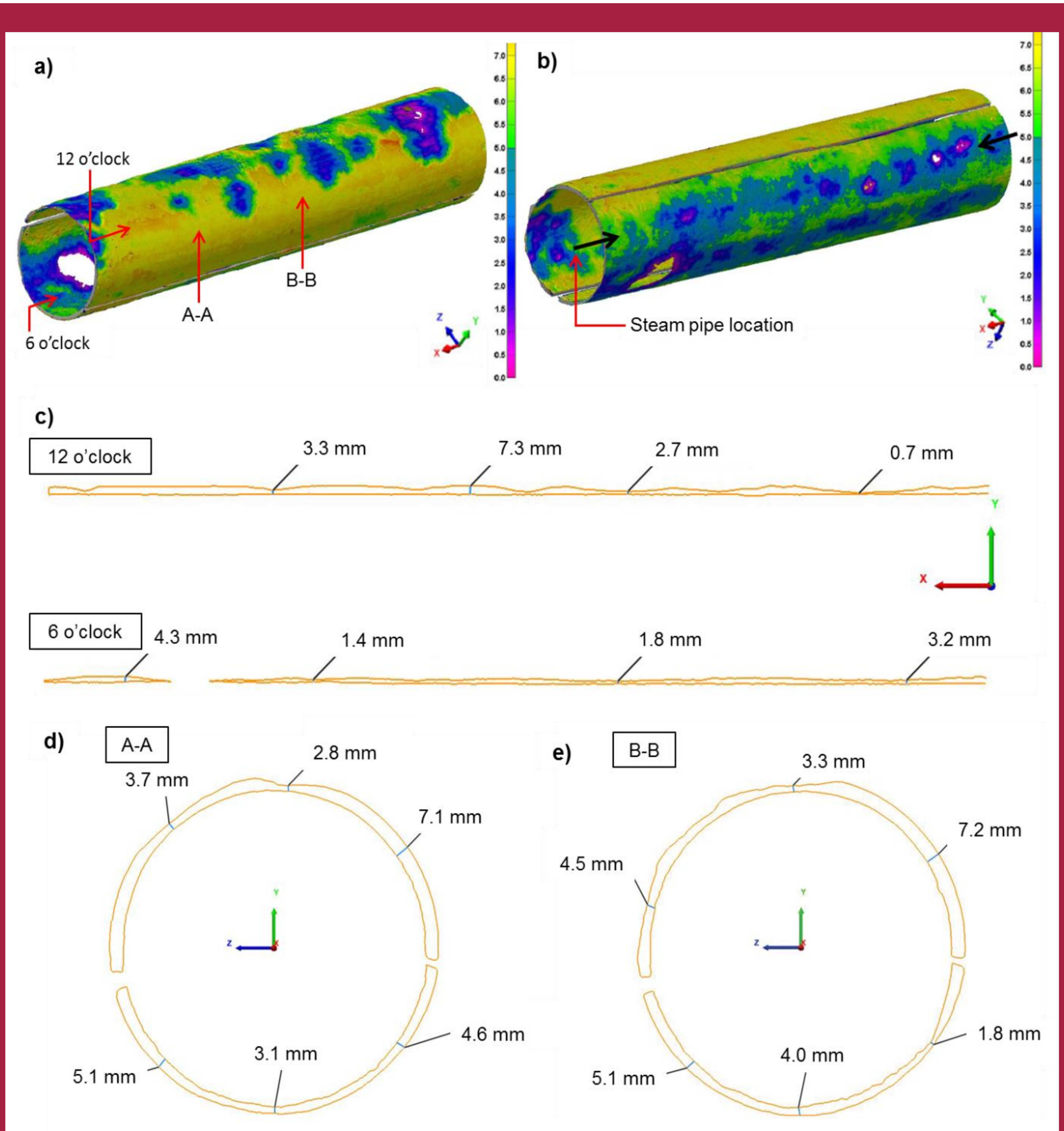


Incident pipe

Non-incident pipe

Laser scanning

- Pipe scan images, a) and b) rotated anti-clockwise through 90 °
- 1m lengths of incident pipe
- Hole at 6 to 8 o'clock
- Steam pipe at 4 o'clock



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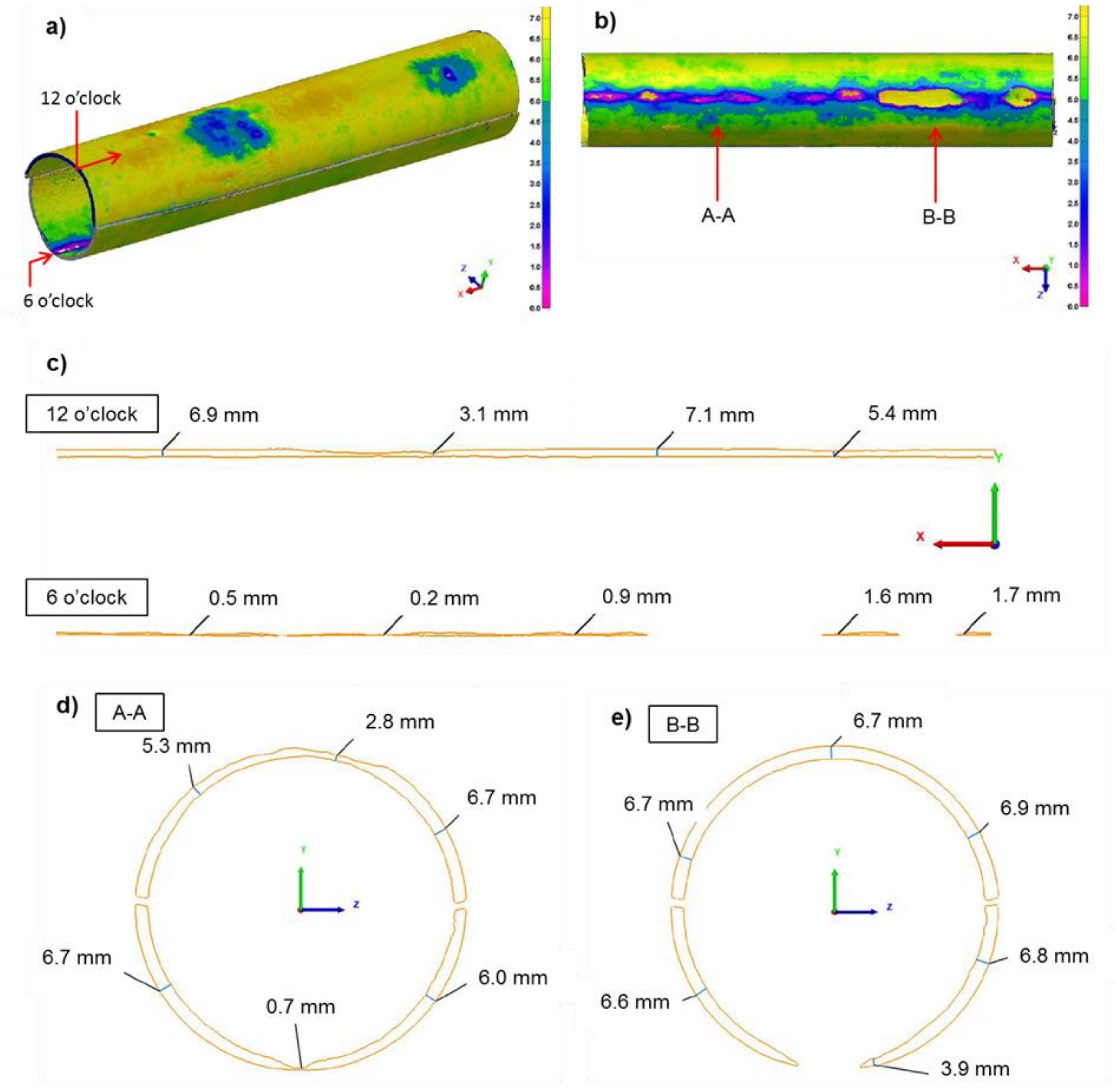
Laser scanning

- Pipe scan images, a) and b) rotated anti-clockwise through 90 °
- 1m lengths of non-incident pipe
- Holes pits and groove at 6 o’clock

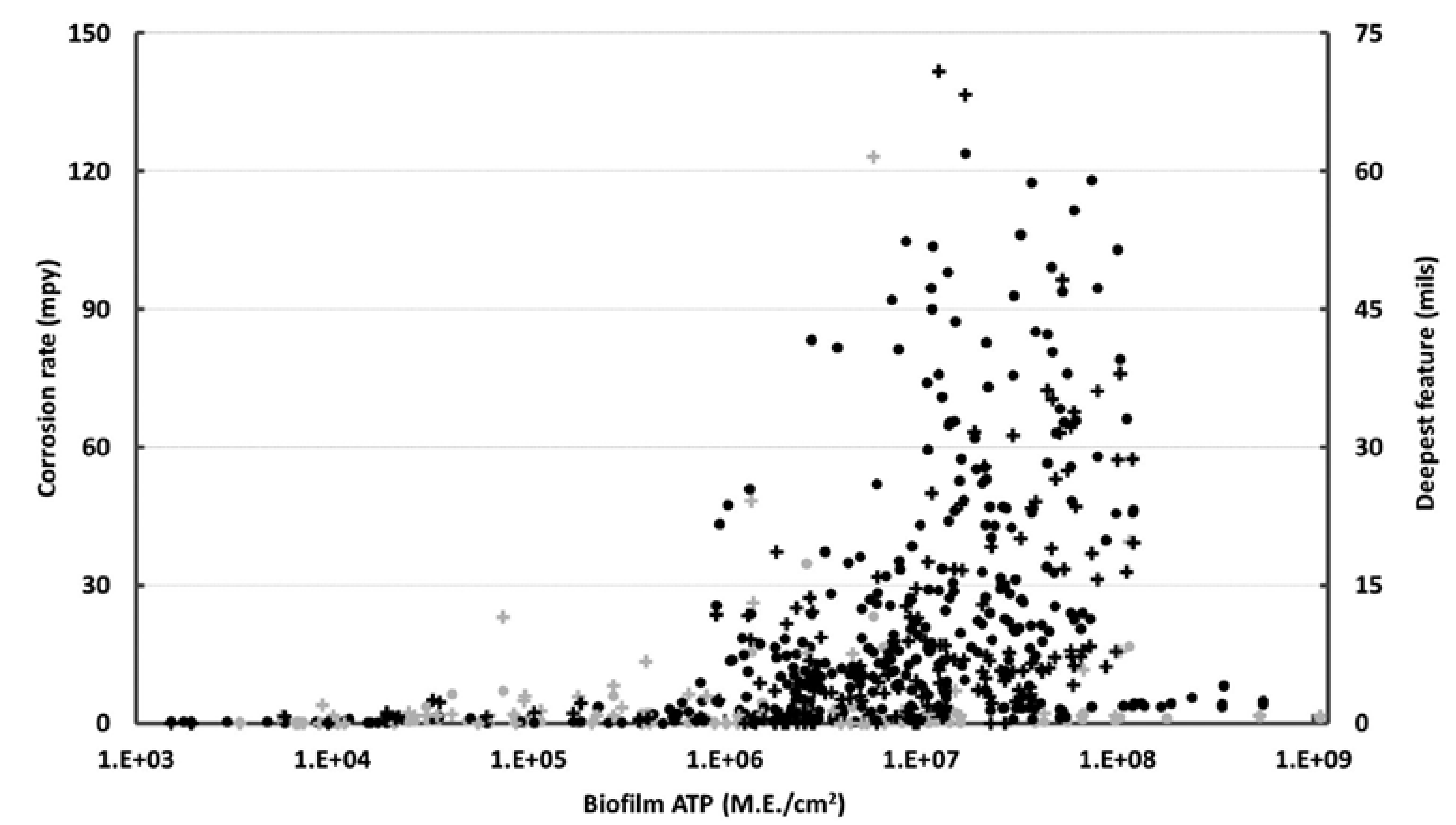


Microbiological analysis

- Three swabs from each pipe from internal surface were taken for qPCR, SRB and SRA
- Two samples from incident pipe near through wall defect showed insufficient DNA for further analysis – possibly affected by decontamination?
- Other swabs showed elevated levels of SRB on non-incident pipe and moderate levels of SRA
- Total bacterial load of 2.0 x 10^6 cells/cm^2 on non-incident pipe.
- SRB: 2.5 x 10^4 cells/cm^2
- SRA: 1.2 x 10^3 cells/cm^2
- Believed to be conservative due to decontamination

In-service monitoring:

- Dutyholders should be mindful of the possibility of MIC in pipelines tanks and vessels
- In-service monitoring techniques are detailed in NACE TM0212-2018
- Use KPIs aligned to the system under review
  - e.g. use microbial monitoring data in conjunction with corrosion data
- High ATP or qPCR tests do not necessarily indicate MIC
- Sample over a period of time to gain statistical reliability
- Consider corrosion test coupons
- If MIC is identified, use mitigation measures and continue monitoring



Ref: NACE TM0212-2018

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Conclusions

- Pipeline material was consistent with API 5L grade B
- Both pipes showed extensive corrosion, paint spalling and significant localised internal and external wall thinning
- Size of defect associated with leak was 73 x 55 mm
- Corrosion at 6 o’clock is common on unprotected steel pipework due to damp conditions caused by shade, poor airflow, vegetation etc.
- Temporary repair clips should be short term. Holes were close to joining up
- The micro-biological load was significant and contributed to failure by MIC, along with other corrosion mechanisms – atmospheric corrosion due to a lack of a protective paint, and possibly CUI

HSE

Thank you for listening

Email: keith.birkitt@hse.gov.uk
aneta.nemcova@hse.gov.uk
ian.chapman@hse.gov.uk

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