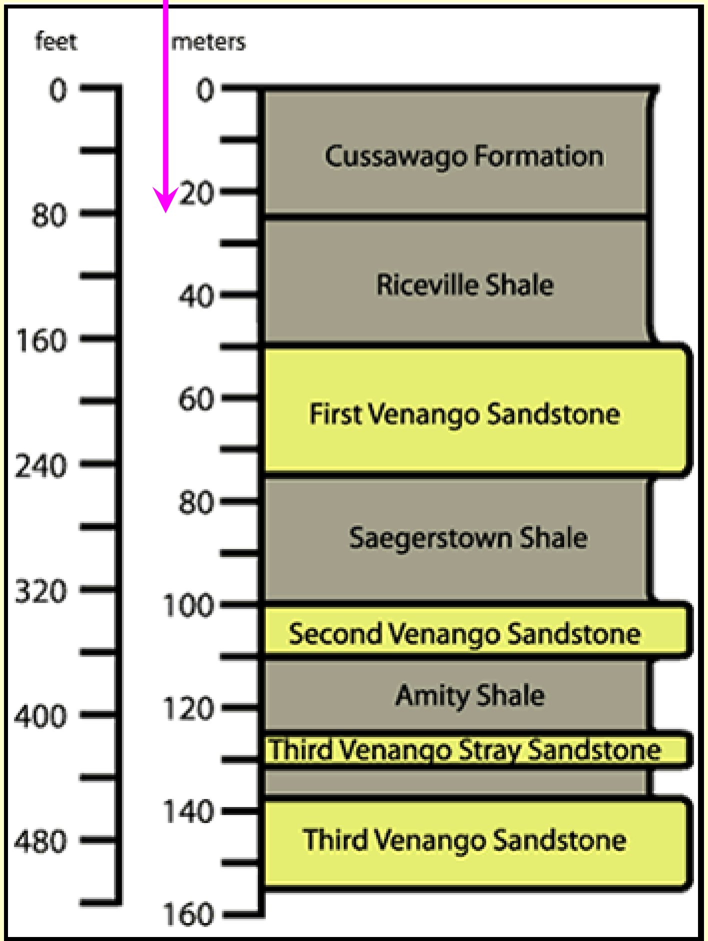
Downhole metallurgy and corrosion – from the first pipe to current challenges.

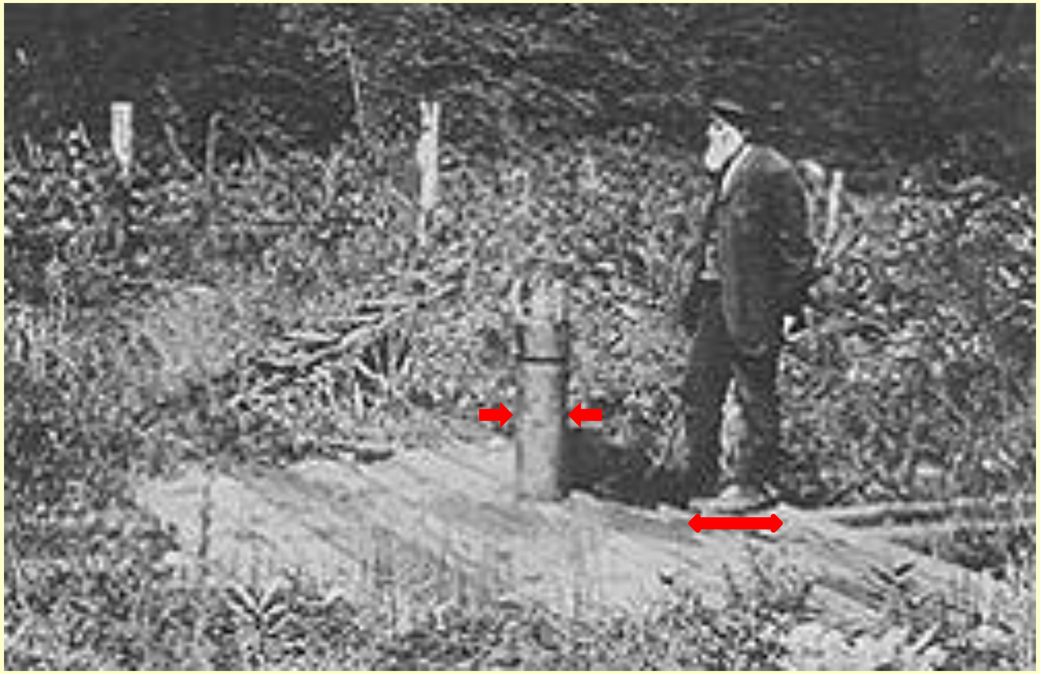
ICorr, IOM3; Aberdeen, 27 November 2018

Drake Well (1859)

TD: 69.5 ft, 21.18 m

....struck oil in the Riceville Shale....
(August 27)





Titusville, Pennsylvania

Abandoned Drake Well in 1896

(Drake Well Museum) ? 12 in boot => ~7 in casing ?

1887: well deepened about 500 ft (153 m).

Hole caved in .... when only 16 ft (4.9 m) deep.

Drake .... idea of drive pipe (conductor .... did not patent!).

Drive pipe: 10 ft joints, cast-iron.

Drove to 'bedrock' at 32 ft (9.8 m) depth.

www.petroleumhistory.org/OilHistory/pages/drake/firstproduction.html

www.priweb.org/ed/pgws/backyard/pennsylvania/pennsylvania_oil2.html

API Pipe history (re strength, SSC, metal-loss)

1st API OCTG Spec (#5): 1924			
1924 to 1940	**Grade**	**SMYS ksi**	**SMTS ksi**
	Wrought iron^	24	42
	Open hearth iron^	25	45
	'steel'^	25	45
	A*	30	48
	B*	35	62
	C*	45	75
1930	D*	55	95
^Lap welded			
	*Seamless, ERW from 1934		

1940 revisions	**Grade**	**SMYS ksi**	**SMTS ksi**
	Wrought iron^	24	42
	Open hearth iron^	25	45
	'steel'^	25	45
	F25^*	25	40
	H40*	40	70
	J55*	55	75
	N80*	80	100
^Lap welded		*Seamless & ERW	

Year	**Grade (SMYS ksi)**	SMYS MPa	**CRA**
1940	H40*	276	
1940	J55*	379	
1940	N80*	552	
1960	P110(*)	758	
1963 - 1990	**C75**	517	
1968	**K55***		
1970 (2011)	C95* (R95)	655	
1972			13Cr trial
1975	(V150)	1034	
1975	**L80***	552	
1984	**C90**	621	
1985	Q125*	862	
1987			L80 9Cr
			L80 13Cr
1989	**T95**	655	
1998	**M65***	448	
2000			ISO 13680
2010			API 5CRA
2011	**C110**	758	

Primary source: Casner Engineering Services, History of API OCTG Grades <https://is.gd/bwJNzK>

Sumitomo SMC110 historical data sheet

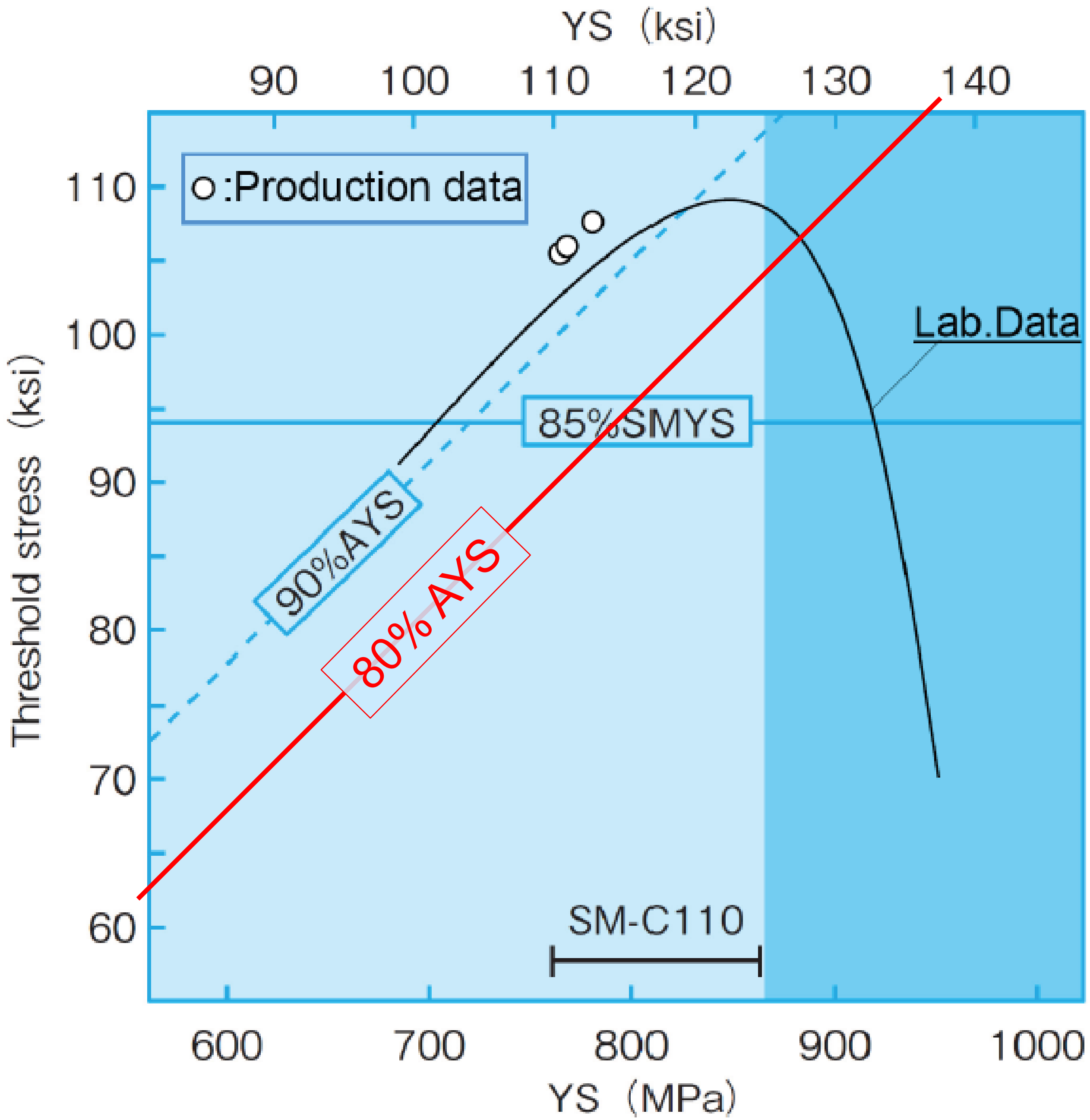


Fig. 3 : SMC110 SSC susceptibility to material Yield Strength and applied threshold stress. NACE Method A, solution A, 25 deg.C.

http://www.sumitomo-tubulars.com/product-services/octg/materials/data-sheet/smc110

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Year	**Grade** (SMYS ksi)	SMYS MPa	**CRA**
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1963 - 1990	**C75**	517	prolonged
1968	**K55***		flow-wetting
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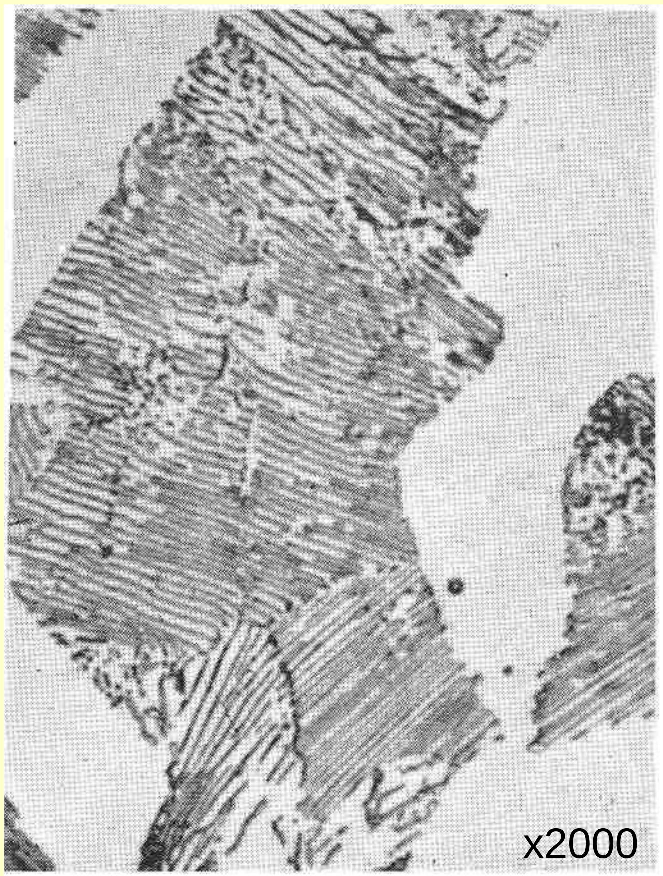
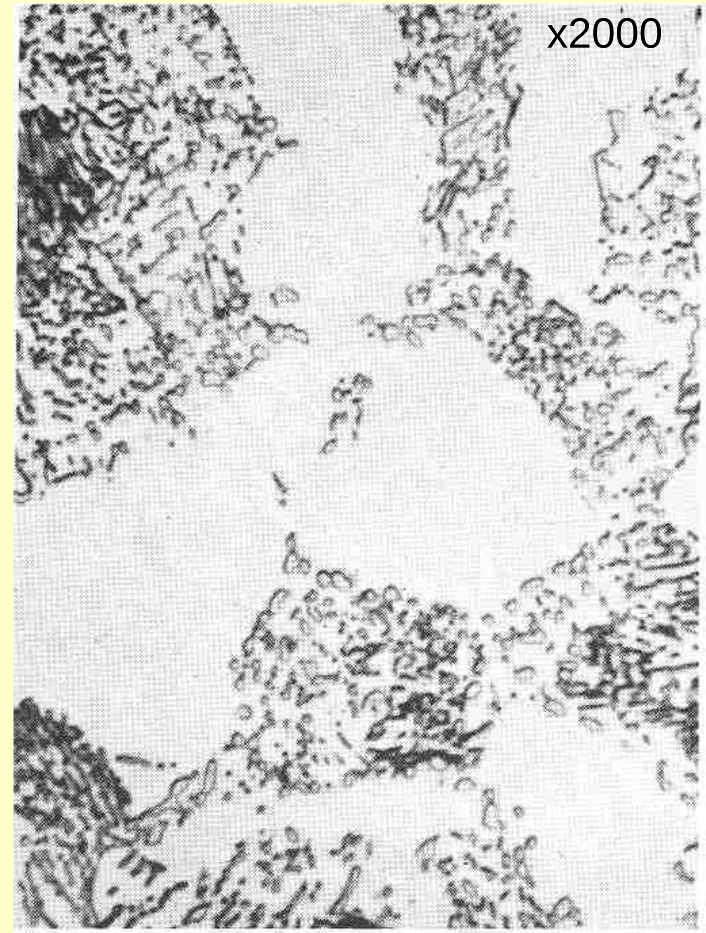
Metal loss as ringworm corrosion of carbon steel

‘GOOD’ pearlite





‘BAD’ pearlite

RINGWORM corrosion only occurs in pearlitic carbon steels (NOT low-alloy steels) after local heat treatment. It has been ‘eliminated’ by the API/ISO requirement for full-length HT.

Microstructures - Manuel, R W: Corrosion, Vol 3, No 9 (1947)
See also for improvement of J55: NACE 2013-2141.

North Sea, metal loss, CRA adoption

1963: NL onshore gas production (Groningen)

1967: UK SNS gas production (BP West Sole)

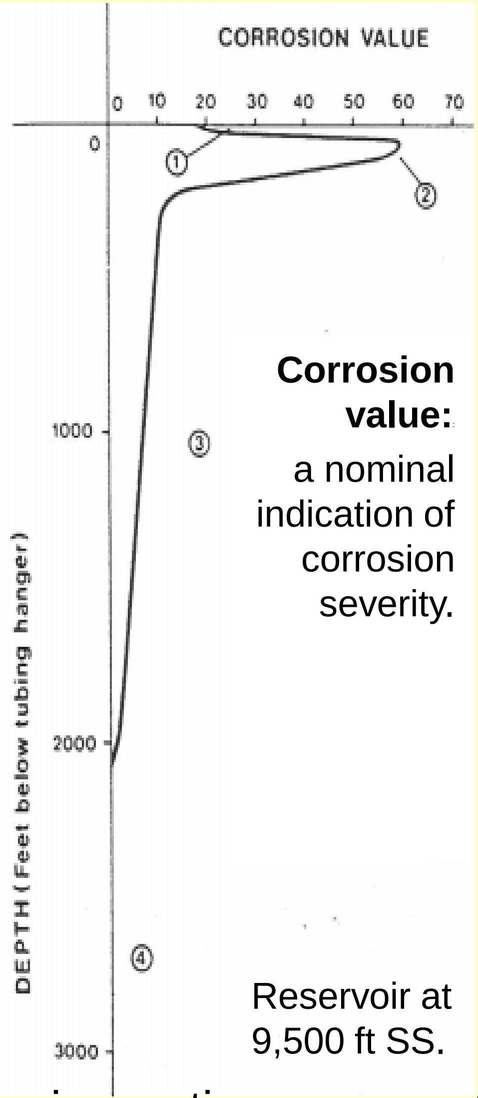
1971: West Sole – tubing failures (N80 after 2~4 years)*****

1972: selective 13Cr tubing in West Sole (and elsewhere)

1972: DK N Sea oil: (CO_2 + MIC, N80/L80 =>2013)

1975: UK oil production

1987: API 5CT additions: L80-9CR, L80-13Cr



Corrosion value: a nominal indication of corrosion severity.

Reservoir at 9,500 ft SS.

String inspection summary*

*****Gair, D J; Moulds, T P: “Tubular corrosion in the West Sole gas field”. SPE Production Engineering, Vol.3, No.2, p.147 (May, 1988).

Cold hardened CRAs for HPHT liners & tubing

Issues:

1) Halite scale potential from high chloride (solids-saturated) formation water.

5 mm thick specimen

2) residual stresses unknown consequences of redistribution during test specimen preparation.

OD: 8.03 in, 204 mm

Options: ignore or investigate?

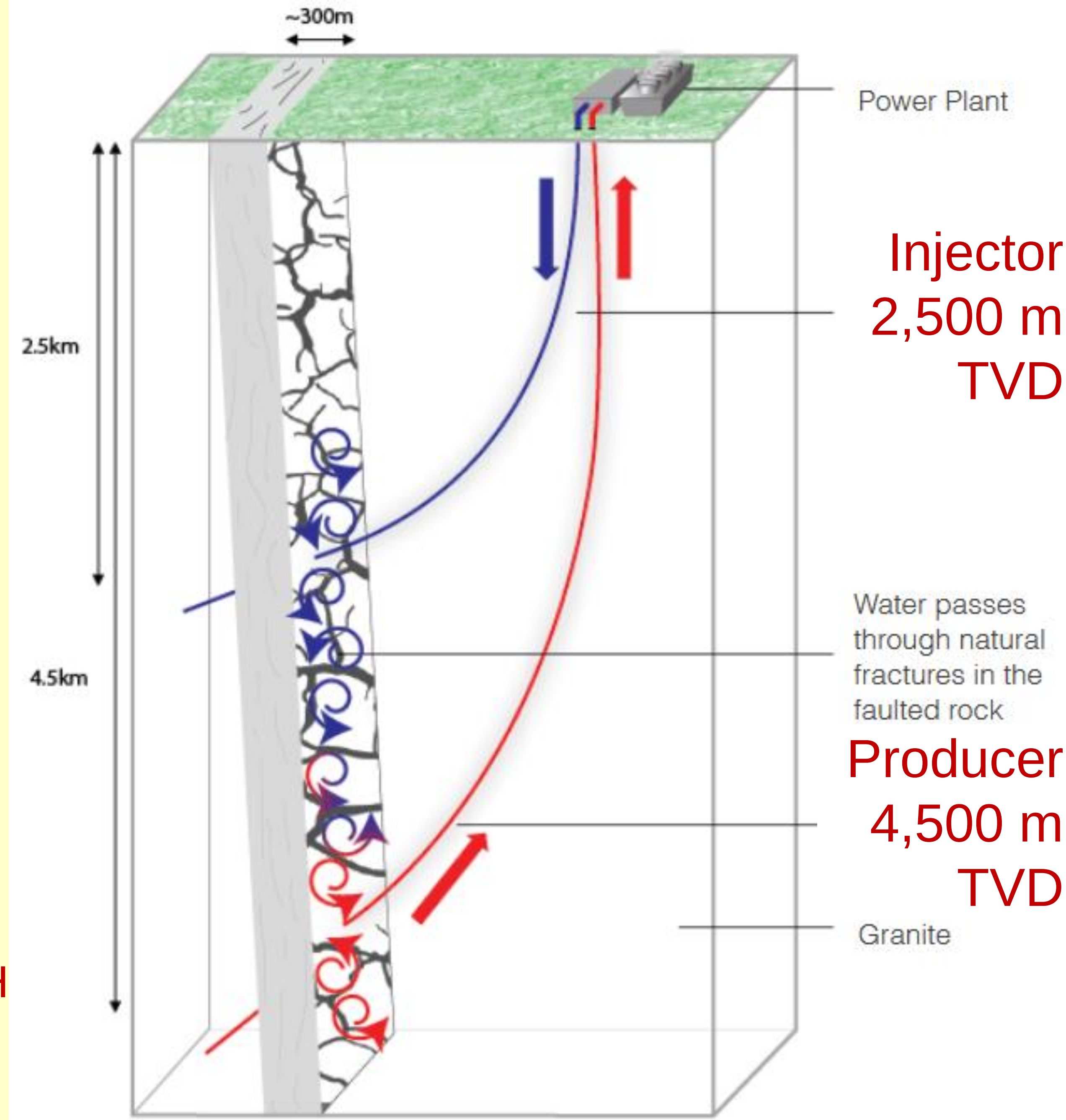
Geothermal

Cornwall: United Downs Deep Power Project

Producer BHT: ~190ºC.

Deepest historical mine: ~1,000 m.

Previously (1980s.): UK H
Dry Rock geothermal research programme.



https://www.uniteddownsgeothermal.co.uk/project-overview

Geothermal Waters, Metallurgy

Waters & contaminants are variable:-

Natural/primary waters (by source): Magmatic, Amagmatic;

by type:

Acid-sulphate:	SO_2, HCl, (NH_4);
Neutral chloride:	CO_2, H_2S, (H_2);
Alkali carbonate:	HCO_3^- ;
Mixed!	

Flow may be NATURAL or ENHANCED by injection / circulation
Hence: Enhanced or Engineered Geothermal Systems (EGS)

Water may change over time.

Sources: Williams, et al: *https://www.energy.gov/.../updating_classification_geothermal_resources_paper.pdf*
EU (GEOCOM) project: www.**geothermal**communities.eu/assets/.../3.2.Corrosion&Scalling.pdf

Metallurgy: any from Oilfield practice (API, ISO) & Ti.
Salton Sea, Ca: Ti-6-4-Ru hot-rolled seamless at 10-3/4, 13-3/8 in OD.
Replaced extruded Ti38644/Pd and thicker 'steel'.
Thomas R: "Titanium in the geothermal industry". GHC Bulletin, December 2003

Carbon Storage

CCS in 3 of 4 IPCC pathways for 1.5ºC

(Oct 2018**)** https://is.gd/BW5zWs

Component	Unit	UK N MAX	UK S MAX	CarbonNet, AU. Lower	CarbonNet, AU. Upper
CO_2	%vol	>0.99	>99.94	93.5	
*N_2, H_2, Ar, CH_4	%vol	0.01			
*N_2, H_2, Ar, O_2, CH_4	%vol	-		2	5
N_2	ppmv	0.006	350		
O_2	ppmv	1	150		
H_2O	ppmv	50	24, (100)		100
CO	ppmv	10		900	5,000
NO_x	ppmv	10		250	2,500
SO_x	ppmv	10		200	2,000
H_2S	ppmv	0.5		100	100
HCl	ppmv	1			
Amines	ppmv	2			
Hg	ppb	1			
NH_4	ppmv	5			
Aldehydes	ppmv	20			
HCN		-		by risk assessment	
Hydrocarbons	ppmv	10			5,000
*'Non-condensables'			(upset)	Lower/Upper: 2 scenarios	

DECC UK Studies:

Longannet => Goldeneye

SSE, Shell

Kingsnorth => Hewett

E.ON, RDS

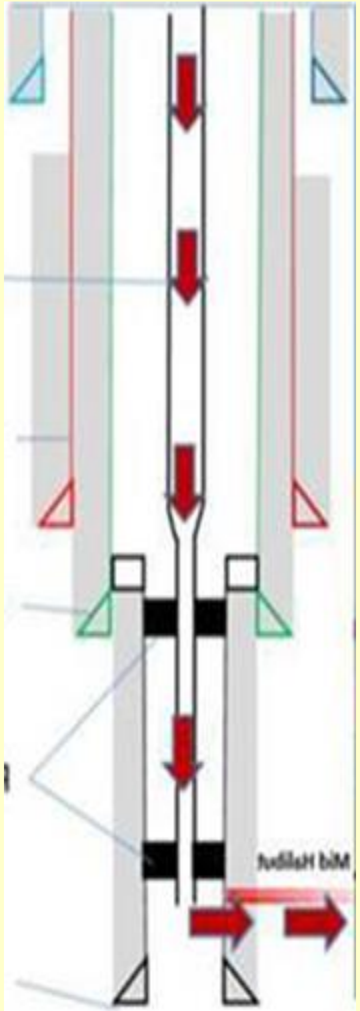
https://is.gd/9ueA8x

CarbonNet, Australia:

Multi-source CO_2 from Victoria's Latrobe Valley to offshore storage in Gippsland Basin.

https://is.gd/E8c1CE

Carbon stores



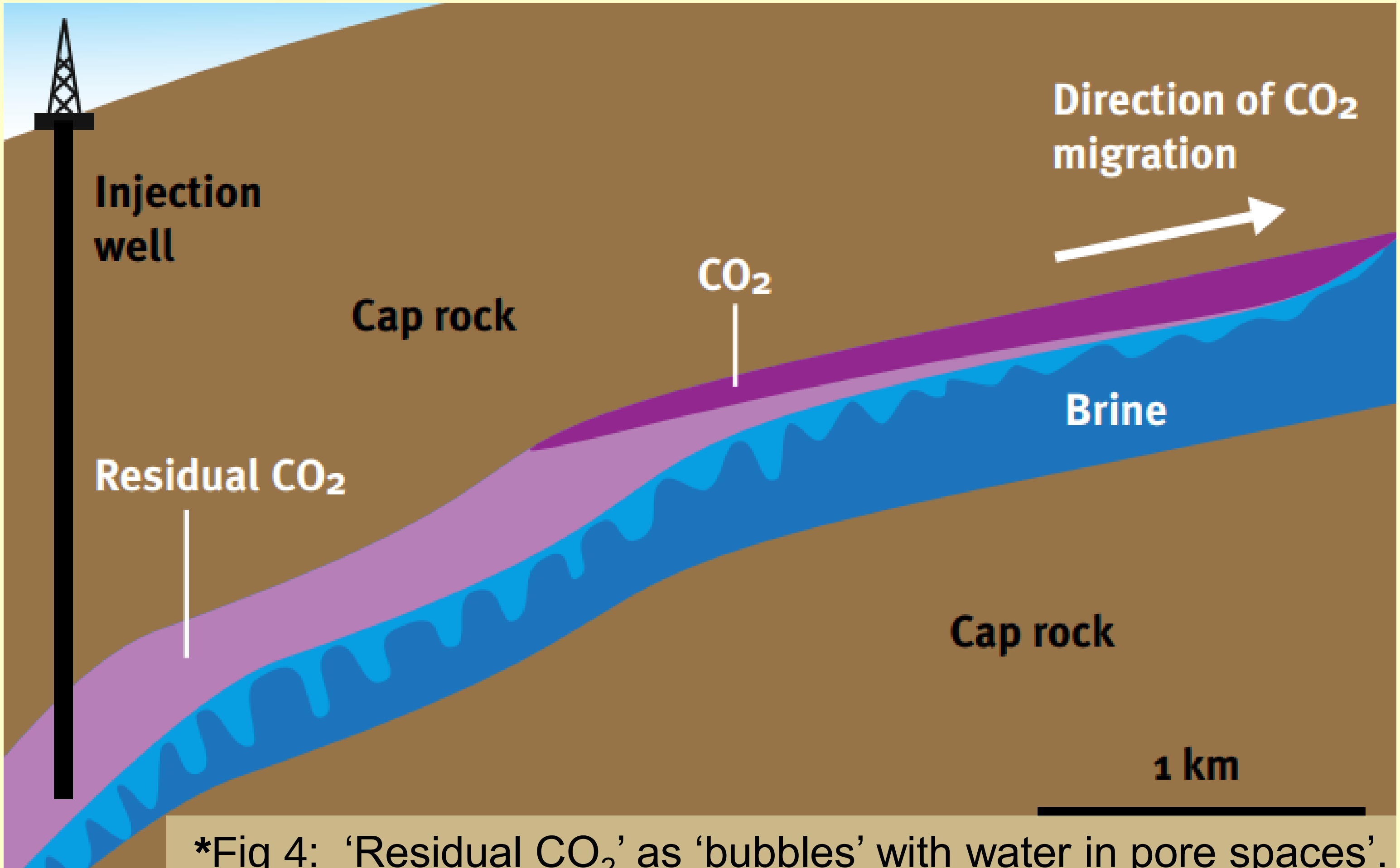


*Fig 4: 'Residual CO_2' as 'bubbles' with water in pore spaces'.

*Imperial College, Grantham Institute for Climate Change; Briefing paper #4 (2010/2011). Carbon dioxide storage, Prof M Blunt.

*Disposal potential: 1 Mt CO_2 per well/y (~19,000 b/d).

6Gt CO_2/y = 50% coal emissions or 20% fossil fuel emissions;

REQUIRES: ~6,000 wells??

see also: 'Mission Possible' from Energy Transitions Commission <http://www.energy-transitions.org/node/45>

Summary

1. 1859~2018: we have been burying metal in wells for 159 years and look like continuing.
2. Downhole metallurgy has been under constant development to meet strength and corrosion challenges.
3. Strength and corrosion resistance continue to challenge oil and gas practice; expect more of the same for carbon-emissions mitigation wells.
4. Lack of deterministic corrosion test protocols is a continuing ‘problem’ for H_2S-resistant low-alloy steels and CRAs. This forces ‘judgemental’ selections.