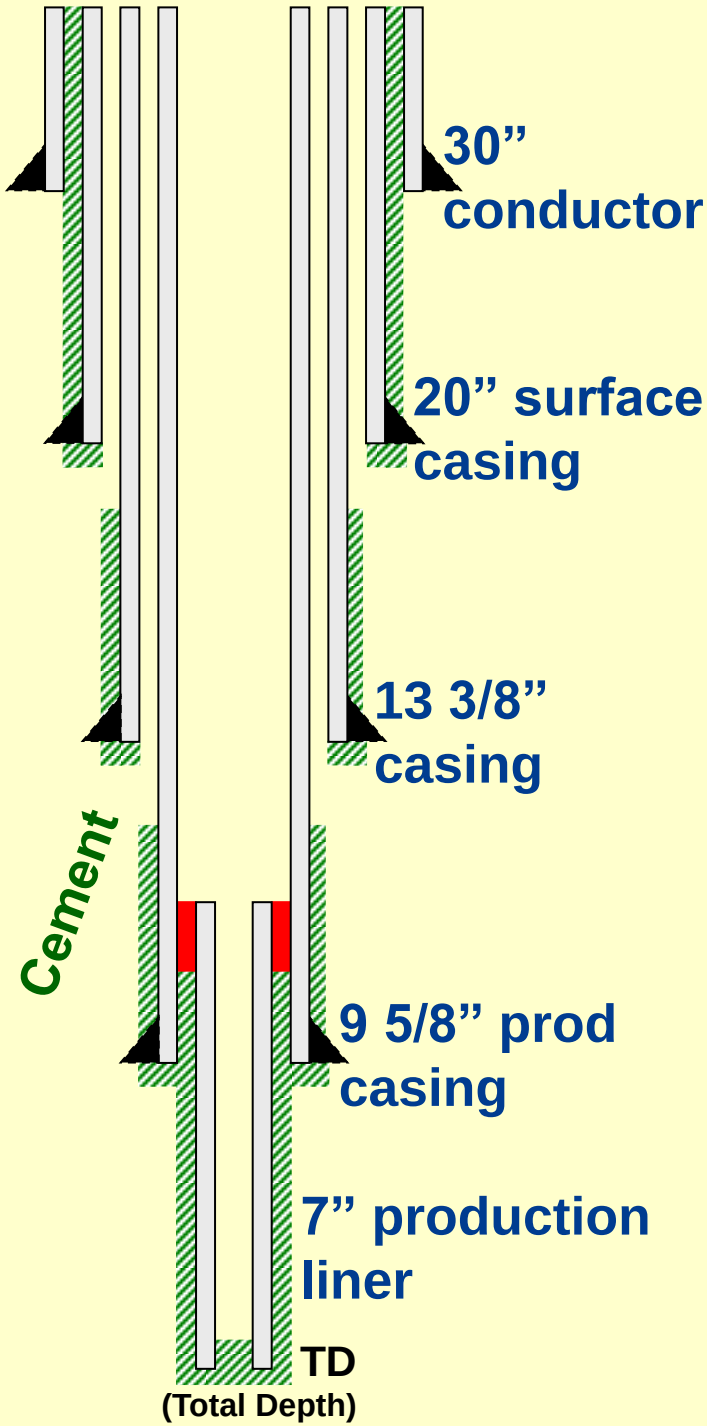
Downhole Metallurgy

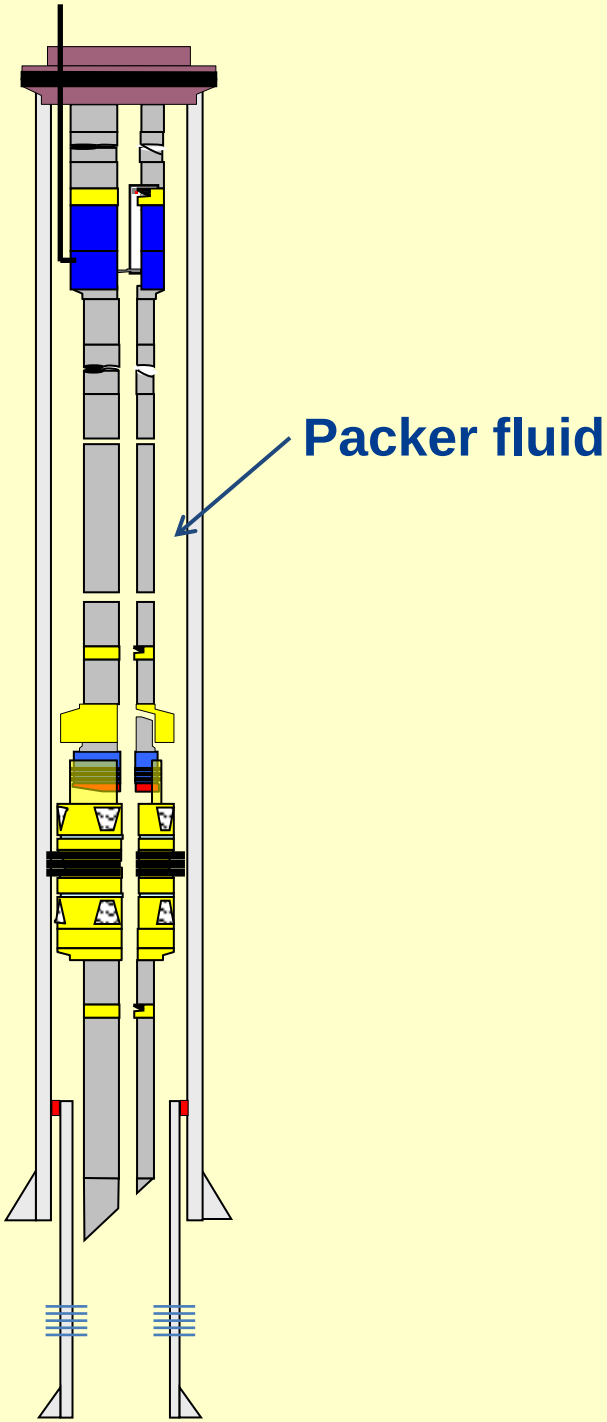
escalating selection challenges

Ed Wade, MetalEcosse Ltd

Welding & Joining Society

Aberdeen, September 2012


30” conductor
20” surface casing
13 3/8” casing
Cement
9 5/8” prod casing
7” production liner
TD
(Total Depth)


Packer fluid

Tubular usage - examples - TONNES

Range: 600 ~ 2,000 tonnes

	CASING Non-flow wetted	TUBING & LINER Flow-wetted	TOTAL tonnes
Clyde A01 14,420 ft	760	147 (16%)	907
Gyda A21 26,597 ft	1,320	208 (14%)	1,528
	Remedial additions to original		226
Erskine W4 18040 ft	1,594	121 (7%)	1,715

API / ISO CASING & TUBING summary

	CARBON STEELS	LOW-ALLOY STEELS	Corrosion Resistant Alloys (CRAs)			
			STAINLESS STEELS			NICKEL ALLOYS
			MARTENSITIC	DUPLEX	AUSTENITIC	
Manufacturing Standard	**API 5CT / ISO 11960:2011**			**ISO 13680:2010** (%Cr-Ni-Mo designations)		
Grades (Sour service grades of carbon and low-alloy steels are shown **bold** - C110 is 'restricted')	**H40** **J55, K55** **M65**	N80-1, N80-Q **L80-1** **C90-1, T95-1** R95 **C110,** P110 Q125	L80-9Cr, L80-13Cr	**Group 1** 13-5-2 13-1-0	**Group 2** 22-5-3 25-7-3 25-7-4 26-6-3	**Group 3** 27-31-4 25-32-3 22-35-4	**Group 4** 21-42-3 22-50-7 25-50-6 20-54-9 22-52-11 15-60-16
SMYS (ksi)	**40, 55, 65**	**80, 90, 95, 110, 125**	**80**	**80, 95, 110**	**(65, 75, 80, 90), 110, 125, 140**	**110, 125, 140**	**110, 125, 140**
Condition	**options per spec HF, N, N&T, Q&T**		**Q&T**		**Cold Hardened (solution annealed)**		

ISO 11960:2011 changed C95 => R95, added C110

Duplex: austenitic/ferritic. SMYS: specified minimum yield strength (room temperature). ksi: 1000 lbf/in^2.

Condition: HF: hot finished; N: normalised; N&T: normalised & tempered; Q&T: quenched & tempered.

Seamless only: L80 9Cr, L80 13Cr, C90, T95, C110; otherwise seamless or 'electric welded'

Not listed: C75, P105, V140/150, ~3%Cr, 316ss, MP35N, Ti alloys!

API / ISO SMYS comparisons

Group	Grade (ksi)	Type	SMYS MPa	SMYS comparisons
1	**H40**		276	**35 ksi -** ASTM A106 B **- process pipework**
	J55		379	**51.5 ksi -** BS 4360 50D **- structural steel**
	K55			
	N80	1	552	**65 ksi -** API 5L X65 **- linepipe**
	N80	Q		
2	**M65**		448	
	L80	**1**	**552**	**80 ksi - X80 on-land gas pipelines**
	C90	**1**	**621**	**- ASTM B7M, L7M - fasteners**
	~~C90~~	~~2~~		**84 ksi -** R4 **- anchor chain**
	C95 / R95			
	T95	**1**	**655**	
	~~T95~~	~~2~~		**102 ksi -** R5 **- anchor chain**
	C110		**758**	**105 ksi -** ASTM B7, L7 **- fasteners**
3	P110		758	
4	Q125	1	862	
	~~Q125~~	~~2, 3, 4~~		**210 ksi - HPHT xtree actuator springs**

GIPS: 245 – 265 ksi, XXGIPS: 315 – 345 ksi

Carbon equivalent
(for weldability)

$$C + \frac{Mn}{6} + \frac{Cu+Ni}{15} + \frac{Cr+Mo+V}{5}$$

Sources of downhole water

Oil wells

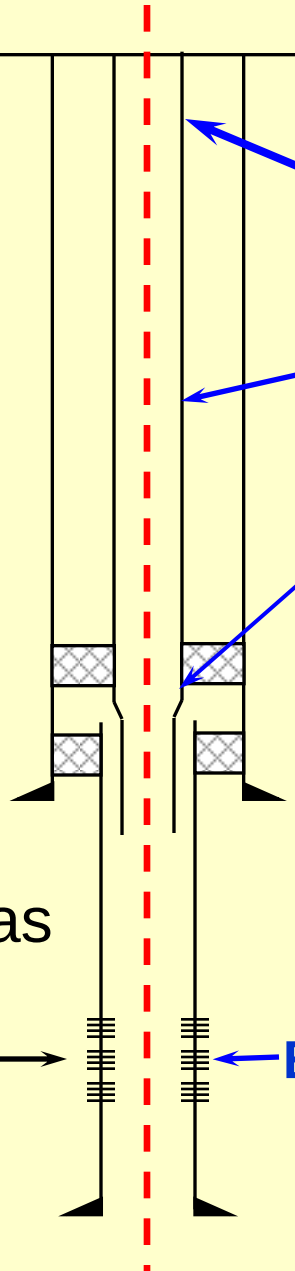
1. Water wetting at all depths (for high water cut).
2. Chlorides (may vary).
3. Bicarbonate (HCO_3^-) dissolved in water buffers CO_2 - pH↑. **pH** usually **>4.5**

LIQUID WATER with salts as

Formation water →

Injection water breakthrough →

Aquifer water →



Gas wells

Water condenses from vapour as it cools

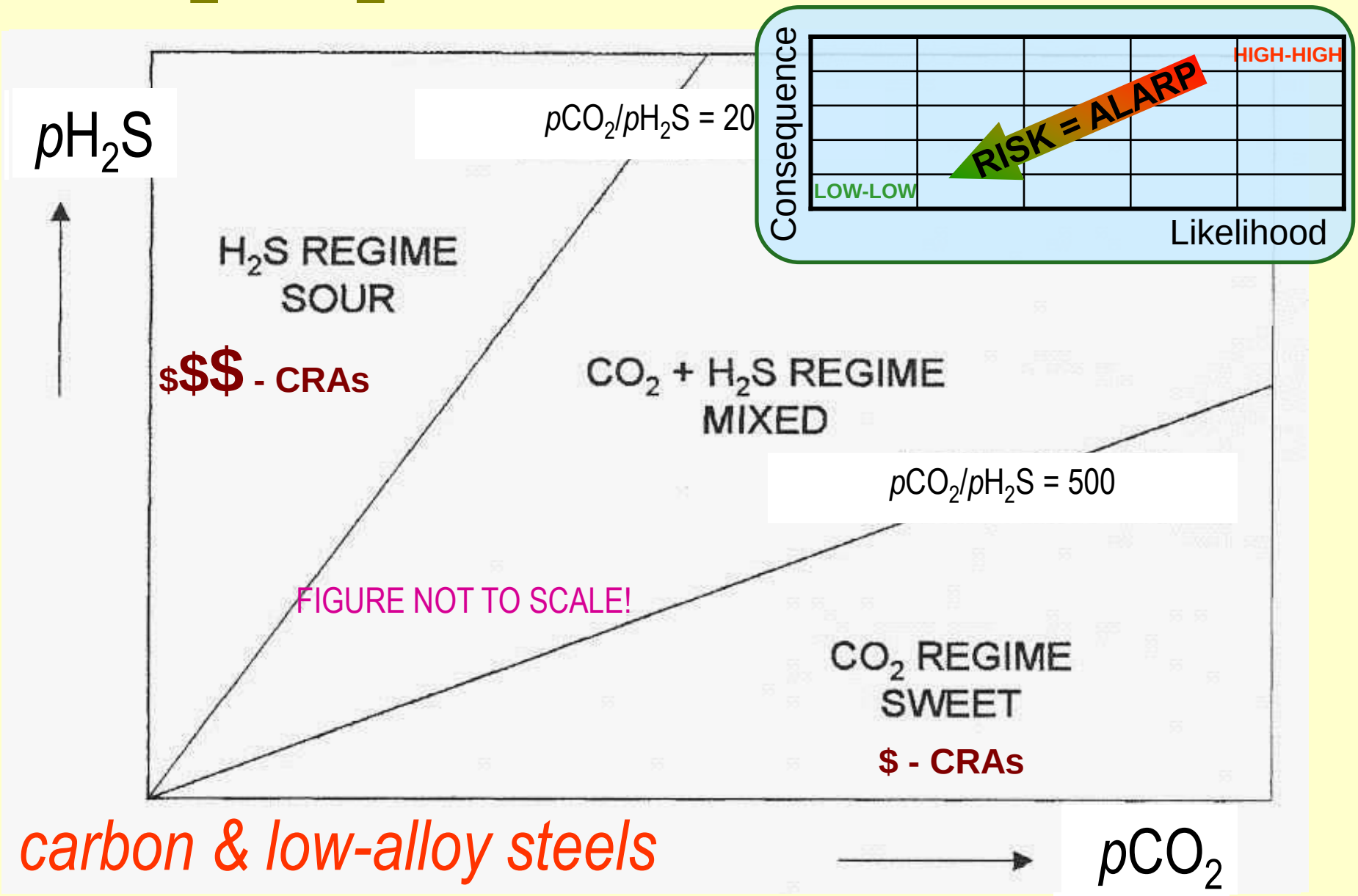
Condensed water

1. Wetting increases towards surface
   - low chloride.
2. No bicarbonate buffer – low pH. **pH** usually **>3.5**

← **Early Life:** water (mostly) as vapour in gas. (Potential for evaporative scaling).

Late life: as for oil well.

CO_2 / H_2S metal-loss regimes

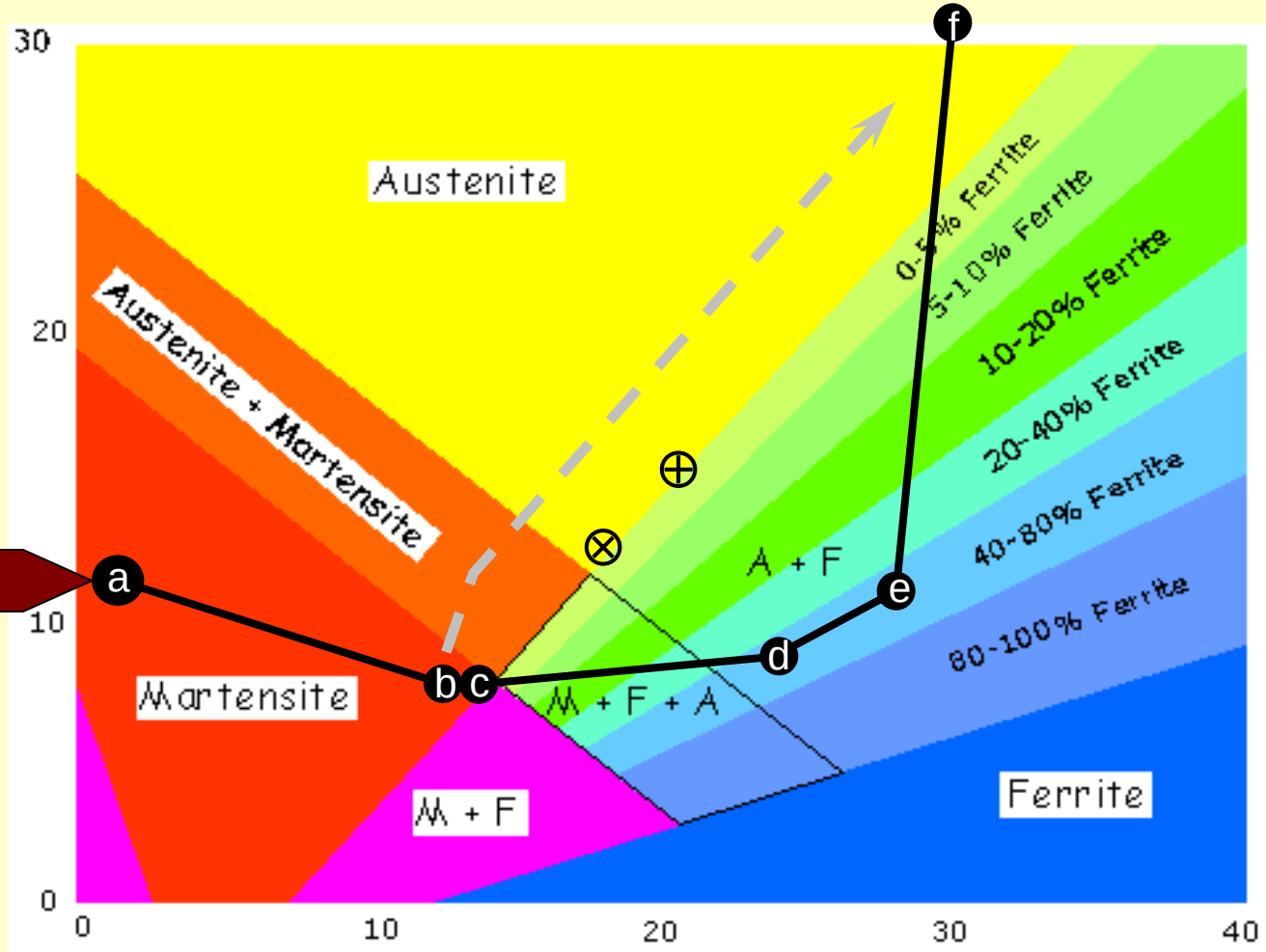


As proposed by Pots et al: NACE Corrosion 2002 paper 235 (#02235)

CRA options (Schaeffler diagram)

Structures of steels fast cooled from 1050ºC

Nickel Equivalent
%Ni + 30*%C + 0.5*%Mn



Key:
a: L80-1
b: L80-13Cr
c: super-13Cr
d: 22Cr DSS
e: super-DSS
f: 27-31-4, 25-32-3
‘the old days’
⊗ 304ss ⊕ 316ss

Chromium Equivalent
%Cr + %Mo + 1.5*%Si + 0.5*%Nb

http://www.gowelding.com/met/diss.html

NACE/ISO: controlling parameters (CRAs)

(to prevent environmental cracking as SSC &/or SCC)

Table A.19 — Environmental and materials limits for martensitic stainless steels used as downhole tubular components and for packers and other subsurface equipment

Specification/ Individual alloy UNS Number	Temperature max. °C (°F)	Partial pressure H_2S, p_{H_2S} max. kPa (psi)	Chloride conc. max. mg/l	pH	Sulfur-resistant? S^0	Remarks
ISO 11960 L-80 Type 13 Cr, S41426, S42500	See remarks	10 (1,5)	See remarks	⩾ 3,5	NDS[a]	Any combinations of temperature and chloride concentration occurring in production environments are acceptable NDS: no data submitted
S41429	See remarks	10 (1,5)	See remarks	⩾ 4,5	NDS[a]	

Environment (Oxygen-free!)

pH from pCO_2, pH_2S, water composition.

Material composition, strength, condition

Strength determines max local tensile stress. (Metals yield!)

~8 primary environmental parameters control cracking……

….and METAL LOSS

CRAs: No metal loss, No cracking

governing temperatures for generic materials

Material	Metal loss	SSC	SSC/SCC	SCC
Carbon & low-alloy steels	varies	Ambient (room) temperature		
Martensitic SS (eg API 13Cr)	maximum service temperature			
Super-martensitic SS (eg super-13Cr)				*maximum service temperature
22%Cr duplex SS			~90°C	
25%Cr super-duplex SS			~120°C	
Super-austenitic SS (eg 28%Cr)				
Nickel alloys				

SS = stainless steel

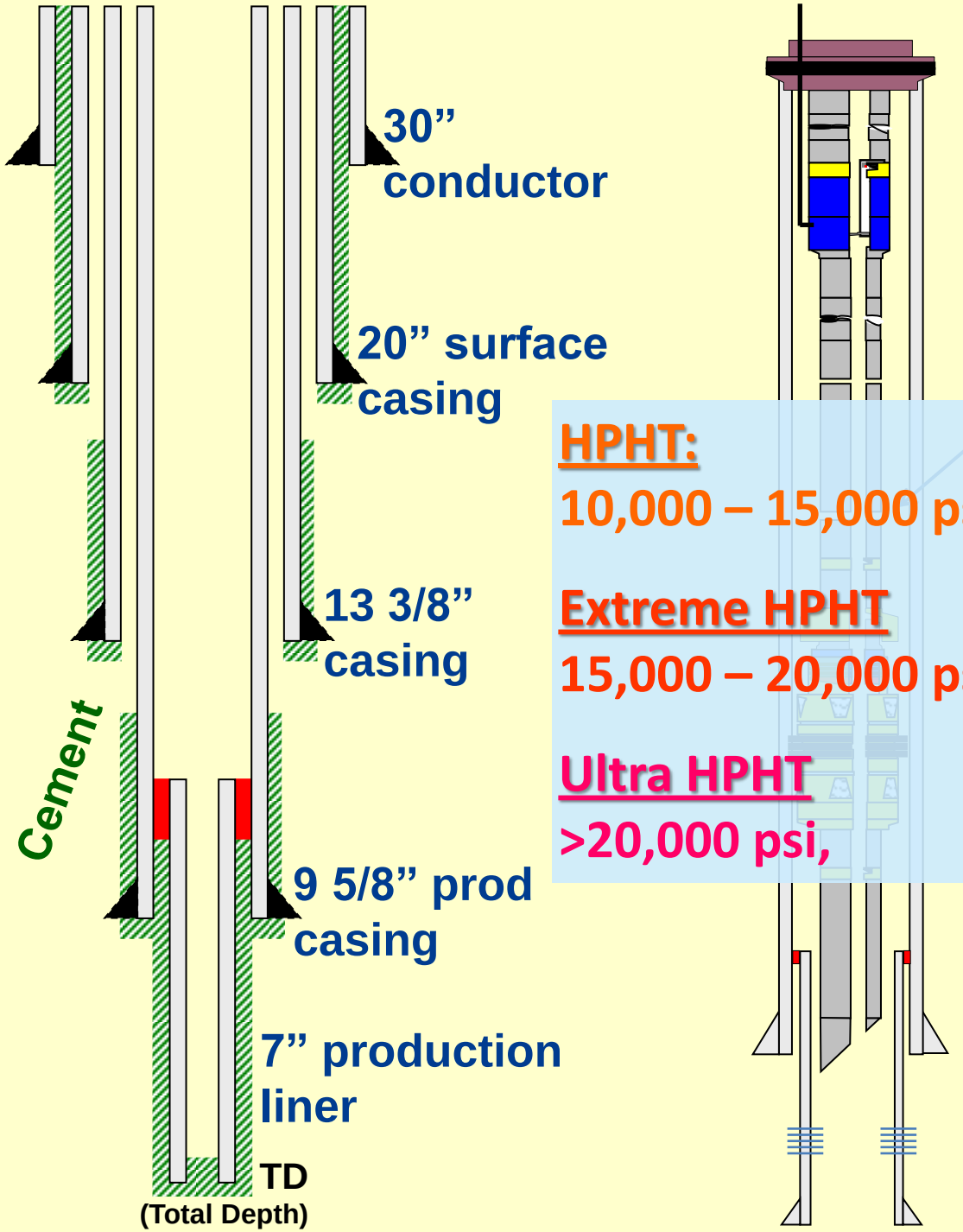
*as precaution for super-martensitic and duplex stainless steels

Primary cases:

Oil production: formation water (then) breakthrough injection water

Gas production: condensed water (then) formation water

Grade (ksi)	SMYS MPa
H40	276
J55	379
K55	
N80-1	552
N80-Q	
M65	448
L80-1	**552**
C90	**621**
C95 / R95	
T95	**655**
C110	**758**
P110	758
Q125	862



HPHT:

10,000 – 15,000 psi, 300 - 350°F

Extreme HPHT

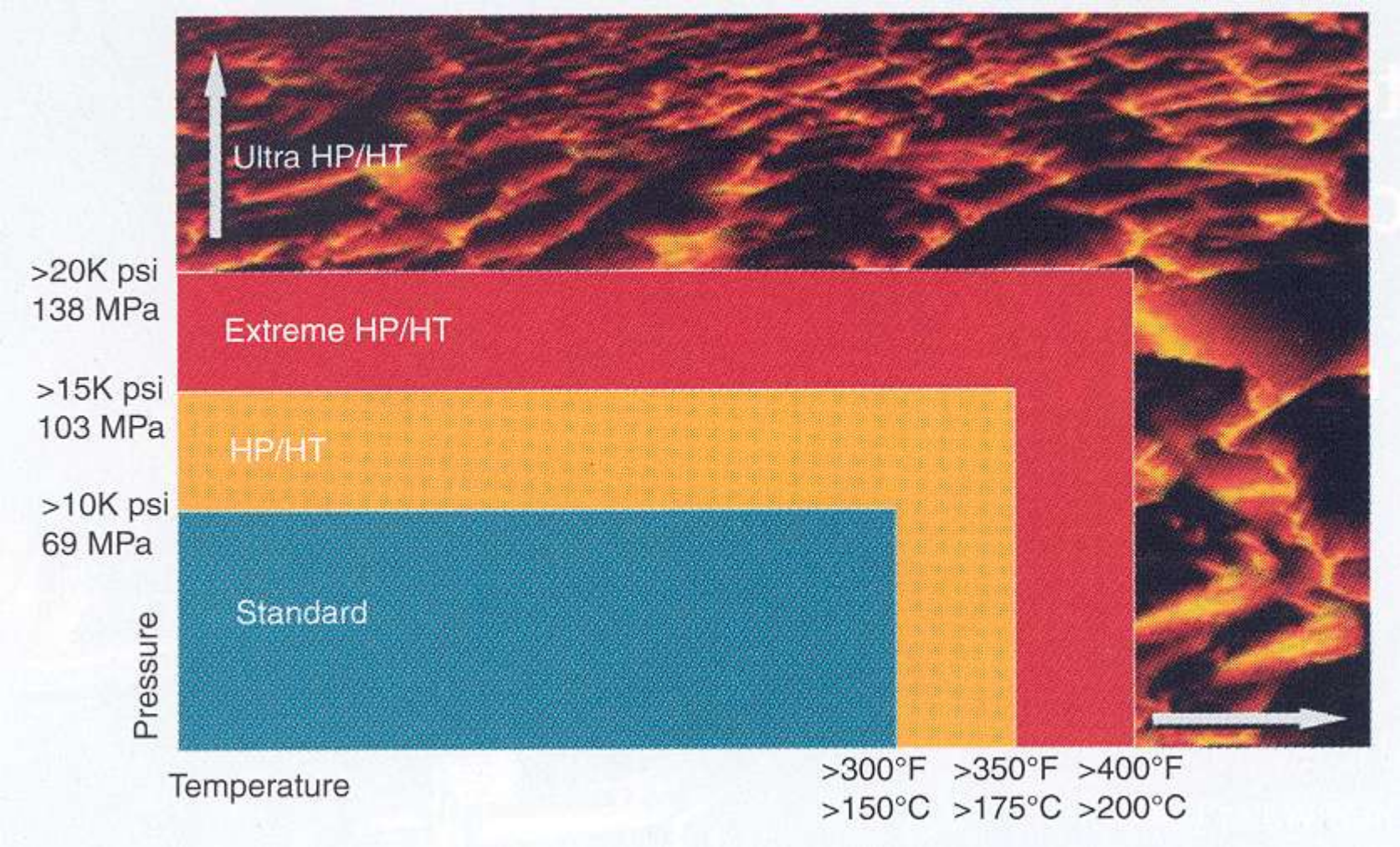
15,000 – 20,000 psi, 350 – 400°F

Ultra HPHT

>20,000 psi, >400°F

HPHT & beyond – definitions

(JPT Jan 2011 p26)



Sumitomo SMC110 data sheet

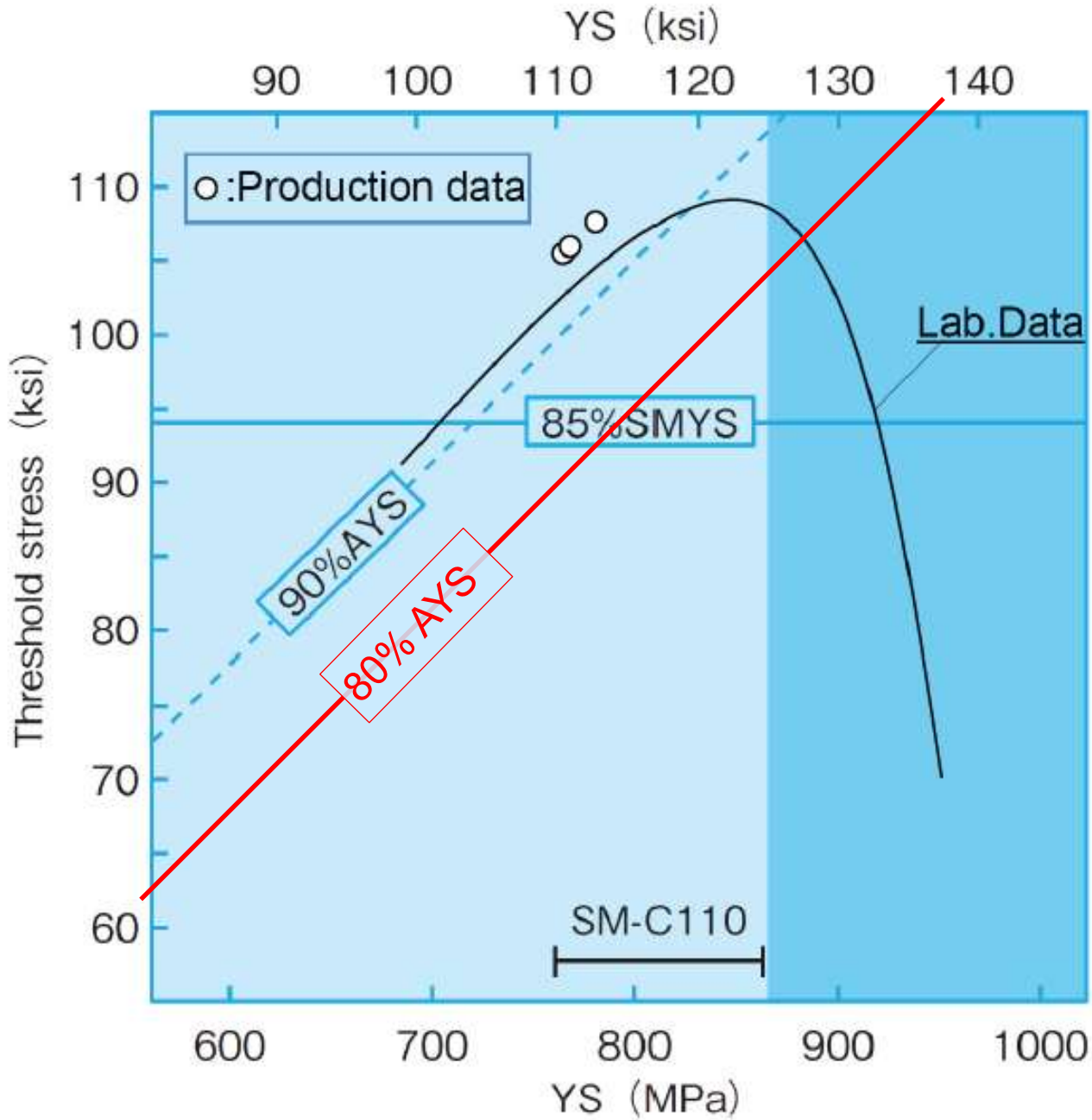


Fig. 3 : SMC110 SSC susceptibility to material Yield Strength and applied threshold stress. NACE Method A, solution A, 25 deg.C.

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

TUBULARS for Exploration & Production wells – NATURAL (& similar) FLUIDS