U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
EBS PANEL MEETING

SUBJECT: ACCELERATED STRESS CORROSION CRACKING STUDIES

PRESENTER: DR. JANG Y. PARK

PRESENTER'S TITLE AND ORGANIZATION: STAFF SCIENTIST, ENERGY TECHNOLOGY DIVISION
ARGONNE NATIONAL LABORATORY
ARGONNE, ILLINOIS

PRESENTER'S TELEPHONE NUMBER: (708) 252-5030

PLEASANTON, CALIFORNIA
MARCH 10-11, 1994

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OBJECTIVES

- Determine susceptibility of candidate waste container materials to stress corrosion cracking in simulated Yucca Mountain ground water.

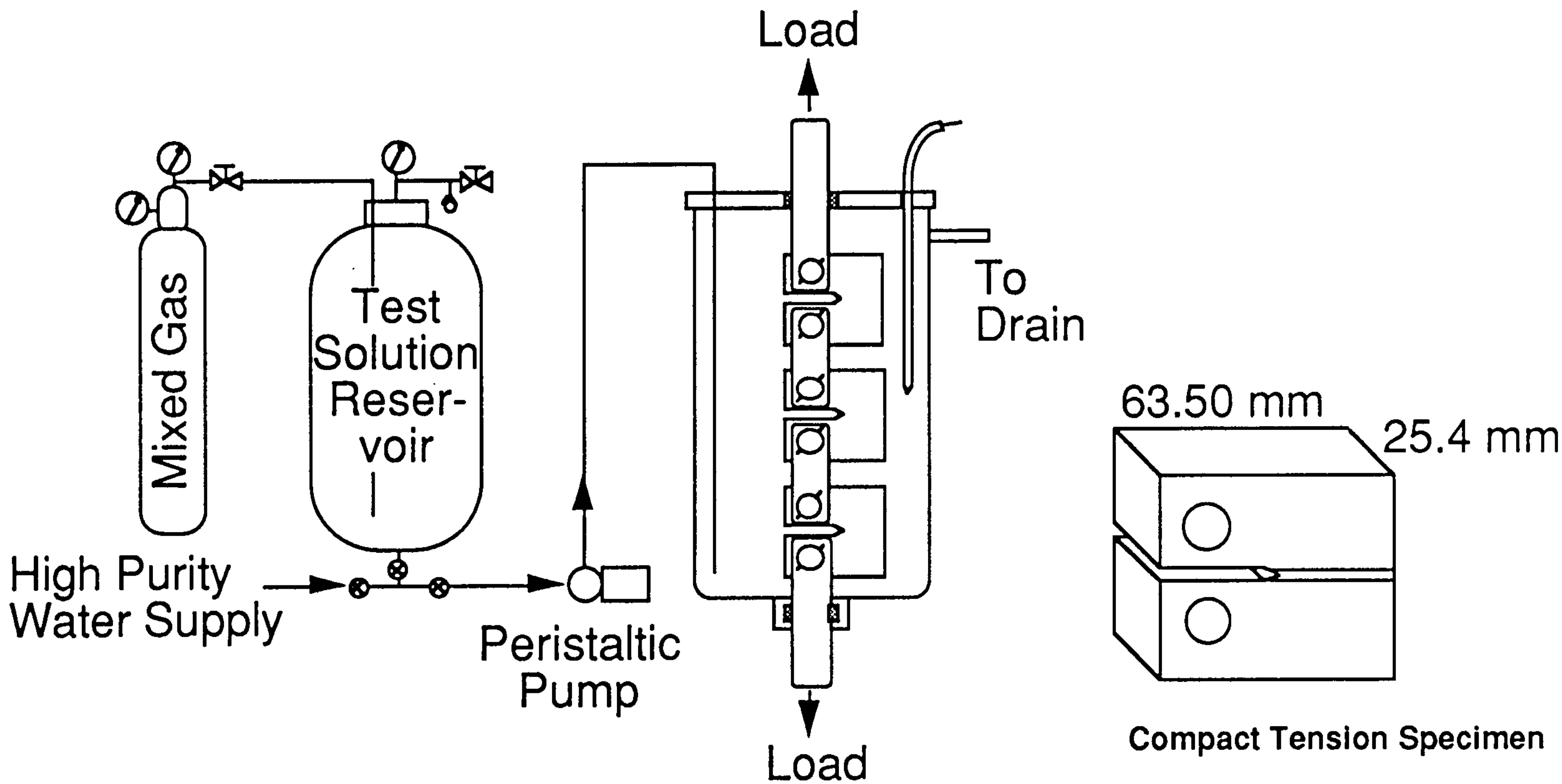
- Provide experimental data base for predictive models for stress corrosion cracking.

Test Materials and Experimental Conditions

Materials:	Incoloy 825, Type 304L SS, and Type 316L SS
Type of Test:	Fracture Mechanics Type Crack Growth Test
Test Specimen:	Modified ASTM E399 specimen 25.4-mm (1-in.) thick compact tension specimen with 1.27-mm (0.05-in.) deep semicircular cross-section side grooves .
Test Temperature:	93°C
Test Vessel:	5-liter nickel vessel once-through flow with rate of 3 ml/min.

Crack-Length Measurement Technique: Electric potential drop

Experimental Setup for Crack–Growth–Rate Tests



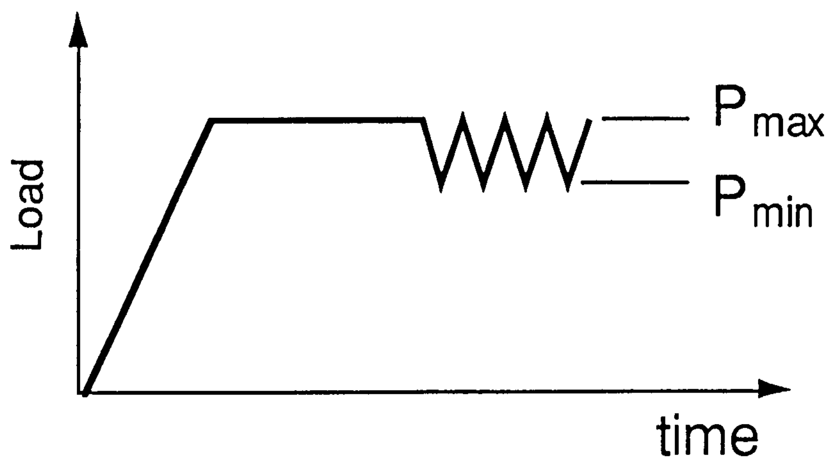
Chemical Composition of J-13 Well Water

Element	Concentration (mg/L)	Species	Concentration (mg/L)
Ca	11.5	F^-	2.1
Mg	1.76	Cl^-	6.4
Na	45.0	SO_4^{2-}	18.1
K	5.3	NO_3^-	10.1
Li	0.06	HCO_3^-	143.0
Fe	0.04	Diss. O_2	5.7
Mn	0.001	$pH_{25°C}$	6.9
Al	0.03		
Si	30.0		

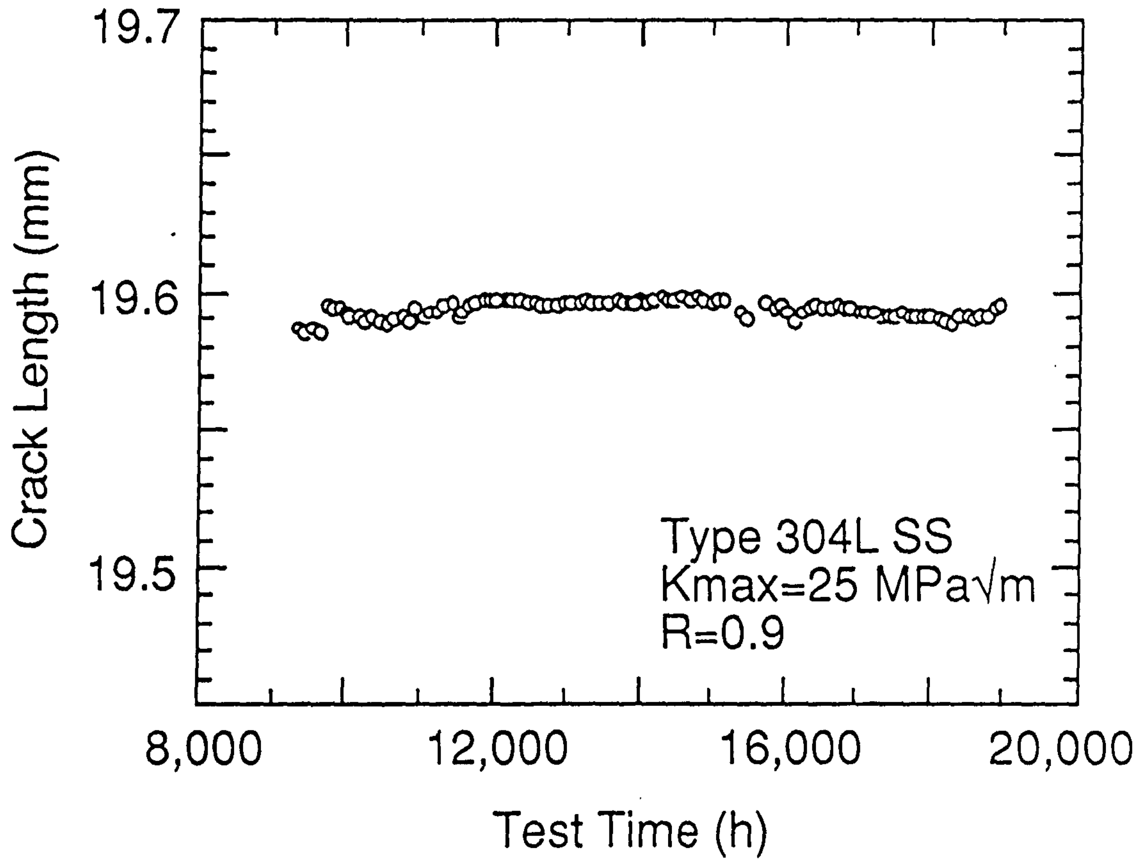
Loading Conditions for Crack-Growth-Rate Tests on Candidate Waste Container Materials

	Load Ratio R	Rise Time (s)	Unloading Time (s)	K_{max} ($MPa \cdot m^{1/2}$)
High R Tests	0.9 - 1.0	12	2	25
Low R Tests	0.2 - 0.7	1 - 5000	1 - 2000	26.8 - 39.8

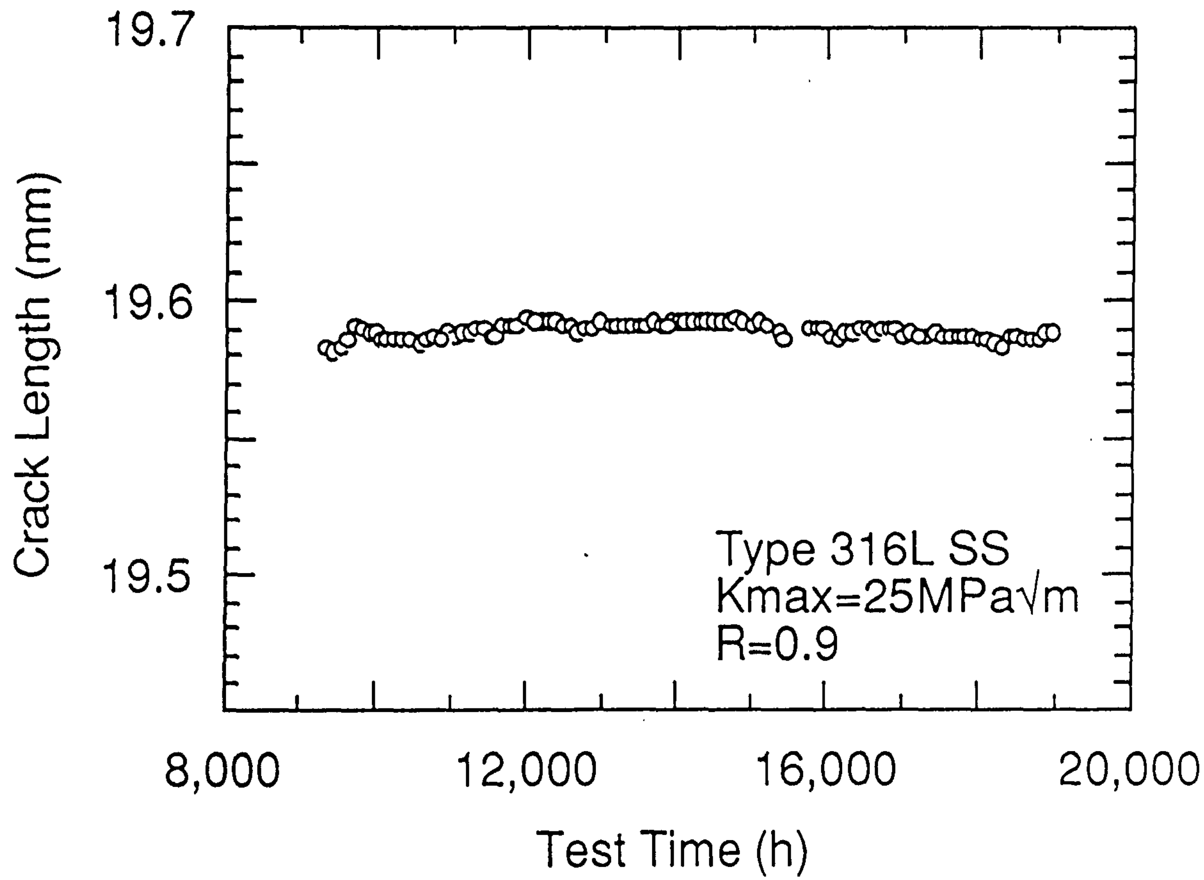
Load Ratio $R = P_{min} / P_{max}$



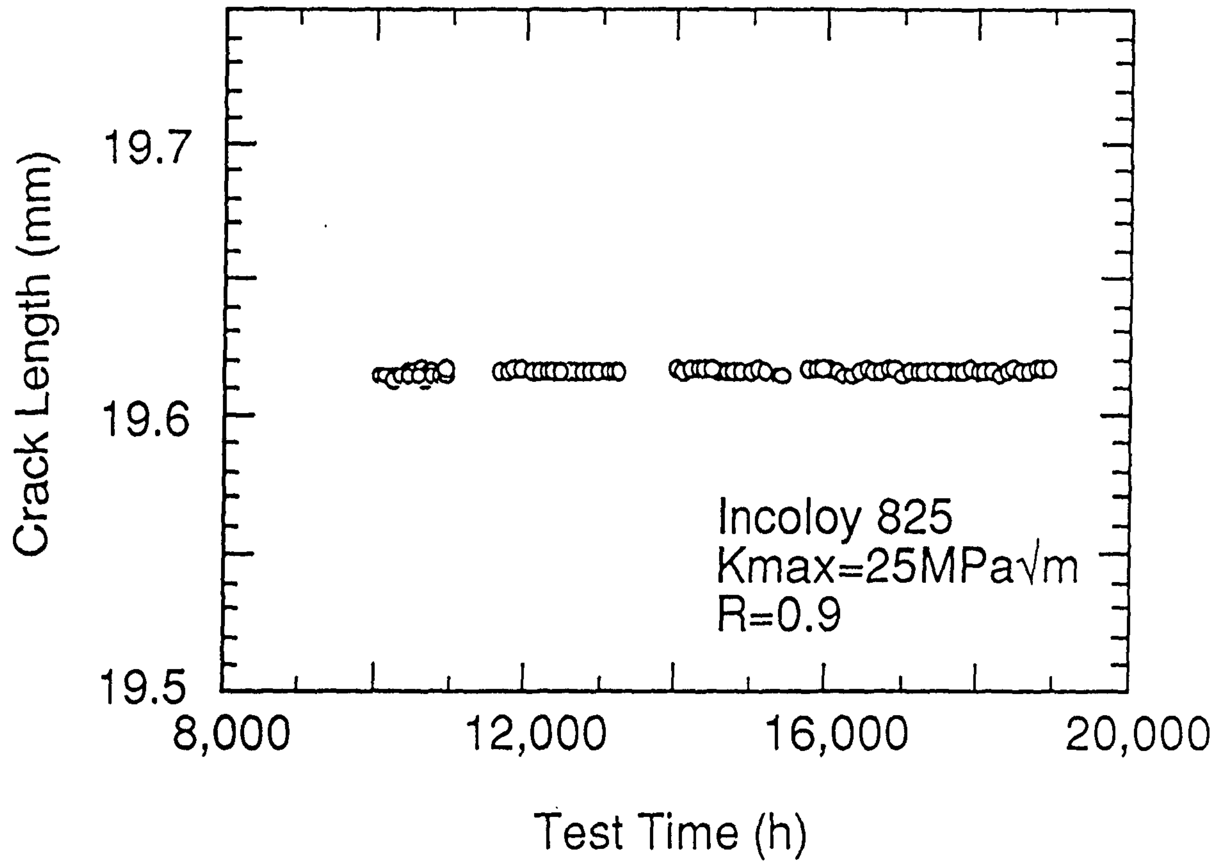
Crack Length vs. Test Time for 304L SS in High–Load–Ratio Test



Crack Length vs. Test Time for 316L SS in High-Load–Ratio Test



Crack Length vs. Test Time for Incoloy 825 in High-Load–Ratio Test



Crack Growth Rate Measured for High-Load-Ratio Tests

CGR_{max}

$$= \frac{\text{Resolution of Measurement}}{\text{Time of Test}}$$

$$= \frac{50 \times 10^{-6}\ \text{m}}{19{,}000\ \text{h}}$$

$$= 8 \times 10^{-13}\ \text{m/s}$$

Maximum Allowable Crack-Growth Rate for 300-Year Life

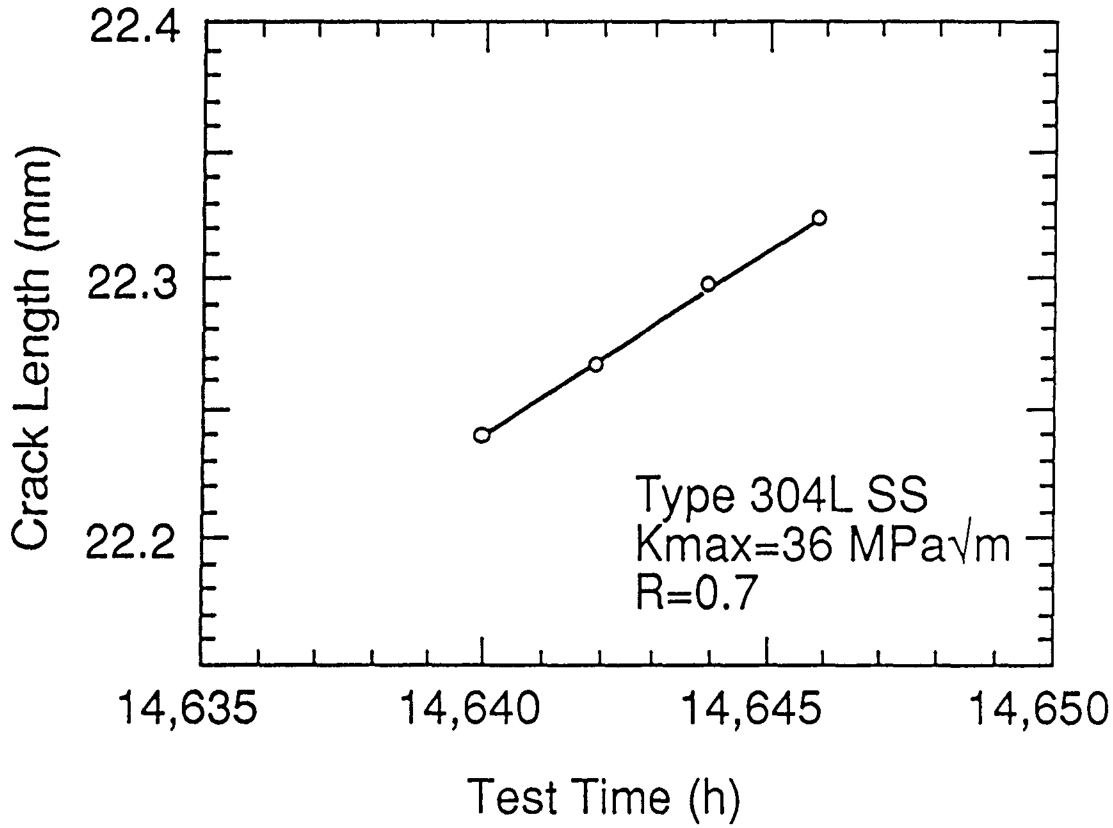
CGR_{max}

$$= \frac{\text{Canister Thickness}}{\text{300 years}}$$

$$= \frac{1 \times 10^{-2}\ \text{m}}{300\ \text{y}}$$

$$= 1 \times 10^{-12}\ \text{m/s}$$

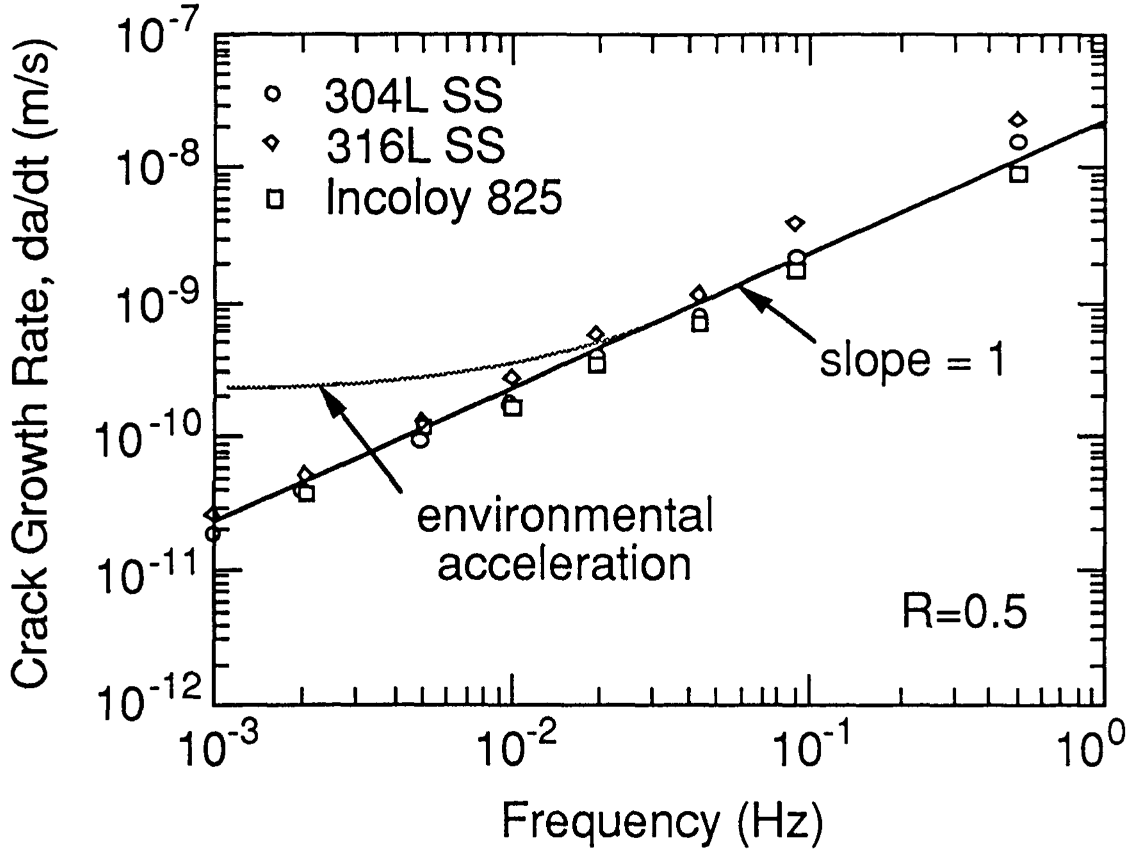
Crack Length vs. Test Time for 304L SS in Low-Load–Ratio Test



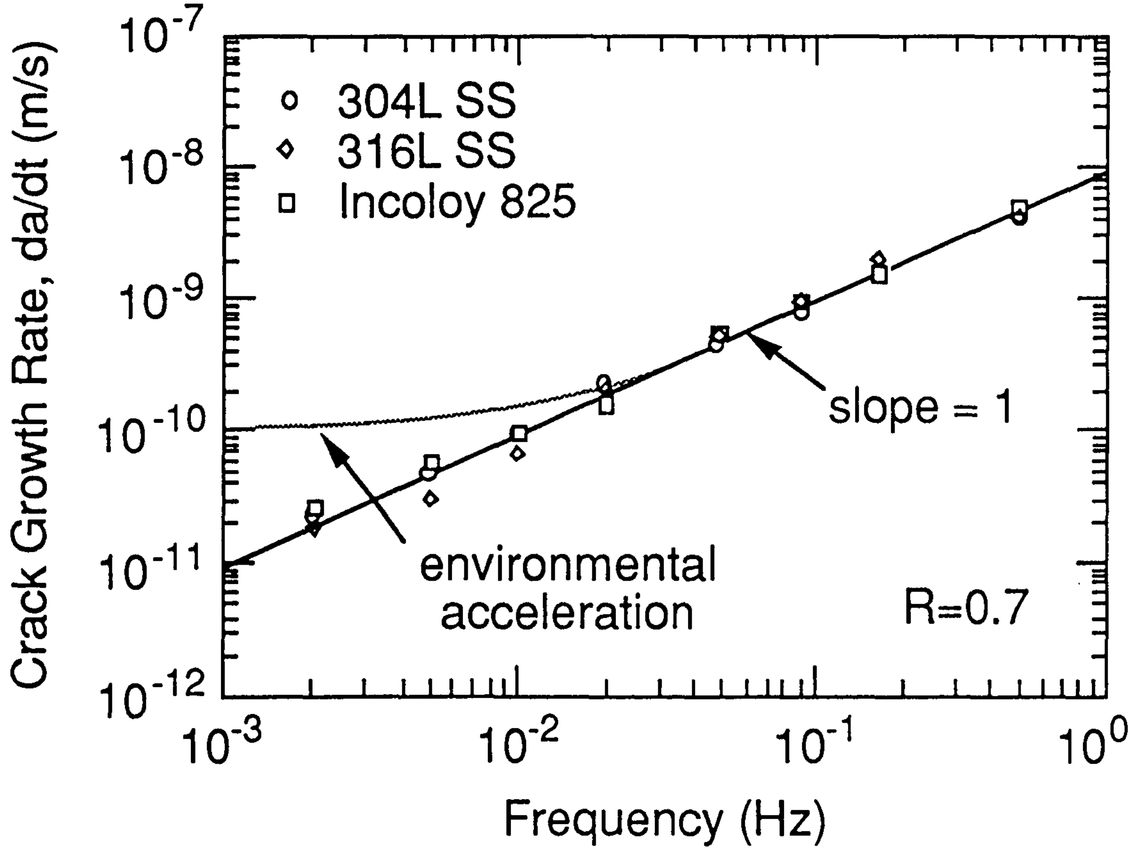
Observed cyclic crack growth rates and rates calculated with ASME Section XI correlation

Load Ratio	Freq. (Hz)	Rise Time (s)	Unload Time (s)	K_{max} (MPa·$m^{1/2}$)	Observed Rate ($m \cdot s^{-1}$)	ASME XI Rate ($m \cdot s^{-1}$)	Ratio (ASME / observed)
304L SS							
0.7	0.500	1	1	35.7	3.96×10^{-9}	8.37×10^{-9}	2.11
0.7	0.167	5	1	35.9	1.62×10^{-9}	2.83×10^{-9}	1.75
0.7	0.091	10	1	36.0	7.64×10^{-10}	1.56×10^{-9}	2.04
0.7	0.048	20	1	36.0	4.41×10^{-10}	8.19×10^{-10}	1.86
0.7	0.020	50	1	36.1	2.31×10^{-10}	3.39×10^{-10}	1.47
0.7	0.010	100	1	36.1	9.73×10^{-11}	1.72×10^{-10}	1.76
0.7	0.005	200	1	36.1	4.91×10^{-11}	8.64×10^{-11}	1.76
0.7	0.002	500	1	36.2	2.29×10^{-11}	3.48×10^{-11}	1.52
0.5	0.500	1	1	27.4	1.55×10^{-8}	1.59×10^{-8}	1.03
0.5	0.091	10	1	27.8	2.15×10^{-9}	3.01×10^{-9}	1.40
0.5	0.048	20	1	28.0	7.89×10^{-10}	1.61×10^{-9}	2.04
0.5	0.020	50	1	28.1	3.96×10^{-10}	6.76×10^{-10}	1.71
0.5	0.010	100	1	28.2	1.78×10^{-10}	3.46×10^{-10}	1.94
0.5	0.005	200	1	28.3	9.40×10^{-11}	1.76×10^{-10}	1.87
0.5	0.002	500	1	28.4	3.94×10^{-11}	7.14×10^{-11}	1.81
0.5	0.001	1000	1	28.5	1.95×10^{-11}	3.59×10^{-11}	1.84
0.2	0.500	1	1	28.8	2.73×10^{-8}	6.29×10^{-8}	2.30
0.2	0.091	10	1	29.6	7.21×10^{-9}	1.25×10^{-8}	1.74
0.2	0.010	100	1	29.7	4.49×10^{-10}	1.38×10^{-10}	3.07
0.2	0.001	1000	1	29.7	3.38×10^{-11}	1.39×10^{-10}	4.12
0.2	0.0002	5000	1	29.7	7.99×10^{-12}	2.79×10^{-11}	3.49
316L SS							
0.7	0.500	1	1	39.2	4.09×10^{-9}	1.14×10^{-8}	2.79
0.7	0.167	5	1	39.4	1.93×10^{-9}	3.87×10^{-9}	2.00
0.7	0.091	10	1	39.6	9.66×10^{-10}	2.13×10^{-9}	2.20
0.7	0.048	20	1	39.6	5.25×10^{-10}	1.12×10^{-9}	2.14
0.7	0.020	50	1	39.7	2.06×10^{-10}	4.64×10^{-10}	2.25
0.7	0.010	100	1	39.7	6.81×10^{-11}	2.35×10^{-10}	3.45
0.7	0.005	200	1	39.7	3.10×10^{-11}	1.18×10^{-10}	3.82
0.7	0.002	500	1	39.8	1.82×10^{-11}	4.76×10^{-11}	2.62
0.5	0.500	1	1	26.8	2.33×10^{-8}	2.02×10^{-8}	0.86
0.5	0.091	10	1	30.0	3.97×10^{-9}	3.88×10^{-9}	0.98
0.5	0.048	20	1	30.3	1.12×10^{-9}	2.10×10^{-9}	1.88
0.5	0.020	50	1	30.6	5.65×10^{-10}	8.91×10^{-10}	1.58
0.5	0.010	100	1	30.8	2.69×10^{-10}	4.60×10^{-10}	1.71
316L SS (cont'd)							
0.5	0.005	200	1	31.0	1.34×10^{-10}	2.36×10^{-10}	1.76
0.5	0.002	500	1	31.1	5.36×10^{-11}	9.58×10^{-11}	1.79
0.5	0.001	1000	1	31.2	2.64×10^{-11}	4.84×10^{-11}	1.83
0.2	0.500	1	1	37.2	7.51×10^{-8}	1.46×10^{-7}	1.95
0.2	0.091	10	1	38.6	2.02×10^{-8}	3.01×10^{-8}	1.49
0.2	0.010	100	1	38.9	1.78×10^{-9}	3.36×10^{-9}	1.89
0.2	0.001	1000	1	39.2	1.77×10^{-10}	3.48×10^{-10}	1.96
0.2	0.0002	5000	1	39.4	4.55×10^{-11}	7.07×10^{-11}	1.56
Incoloy 825							
0.7	0.500	1	1	36.4	4.89×10^{-9}	8.86×10^{-9}	1.81
0.7	0.167	5	1	36.6	1.56×10^{-9}	3.01×10^{-9}	1.93
0.7	0.091	10	1	36.7	9.55×10^{-10}	1.66×10^{-9}	1.74
0.7	0.048	20	1	36.7	5.28×10^{-10}	8.74×10^{-10}	1.66
0.7	0.020	50	1	36.8	1.60×10^{-10}	3.61×10^{-10}	2.26
0.7	0.010	100	1	36.8	9.73×10^{-11}	1.83×10^{-10}	1.88
0.7	0.005	200	1	36.9	5.84×10^{-11}	9.23×10^{-11}	1.58
0.7	0.002	500	1	36.9	2.62×10^{-11}	3.72×10^{-11}	1.42
0.5	0.500	1	1	27.4	9.05×10^{-9}	1.58×10^{-8}	1.75
0.5	0.091	10	1	27.6	1.70×10^{-9}	2.96×10^{-9}	1.74
0.5	0.048	20	1	27.8	7.04×10^{-10}	1.58×10^{-9}	2.25
0.5	0.020	50	1	27.9	3.54×10^{-10}	6.61×10^{-10}	1.87
0.5	0.010	100	1	28.1	1.67×10^{-10}	3.39×10^{-10}	2.03
0.5	0.005	200	1	28.2	1.22×10^{-10}	1.72×10^{-10}	1.41
0.5	0.002	500	1	28.3	3.88×10^{-11}	6.99×10^{-11}	1.80
0.2	0.500	1	1	29.9	2.99×10^{-8}	7.12×10^{-8}	2.38
0.2	0.091	10	1	30.8	7.13×10^{-9}	1.43×10^{-8}	2.00
0.2	0.010	100	1	30.9	7.62×10^{-10}	1.57×10^{-9}	2.06
0.2	0.001	1000	1	31.0	7.01×10^{-11}	1.60×10^{-10}	2.29
0.2	0.0002	5000	1	31.0	1.75×10^{-11}	3.21×10^{-11}	1.83
0.2	0.091	10	1	31.5	7.24×10^{-9}	1.54×10^{-8}	2.12
0.2	0.067	10	5	31.7	4.74×10^{-9}	1.15×10^{-8}	2.43
0.2	0.033	10	20	31.8	2.55×10^{-9}	5.82×10^{-9}	2.28
0.2	0.009	10	100	31.9	7.71×10^{-10}	1.60×10^{-9}	2.08
0.2	0.002	10	500	31.9	1.53×10^{-10}	3.46×10^{-10}	2.26
0.2	0.0005	10	2000	31.9	4.32×10^{-11}	8.77×10^{-11}	2.03

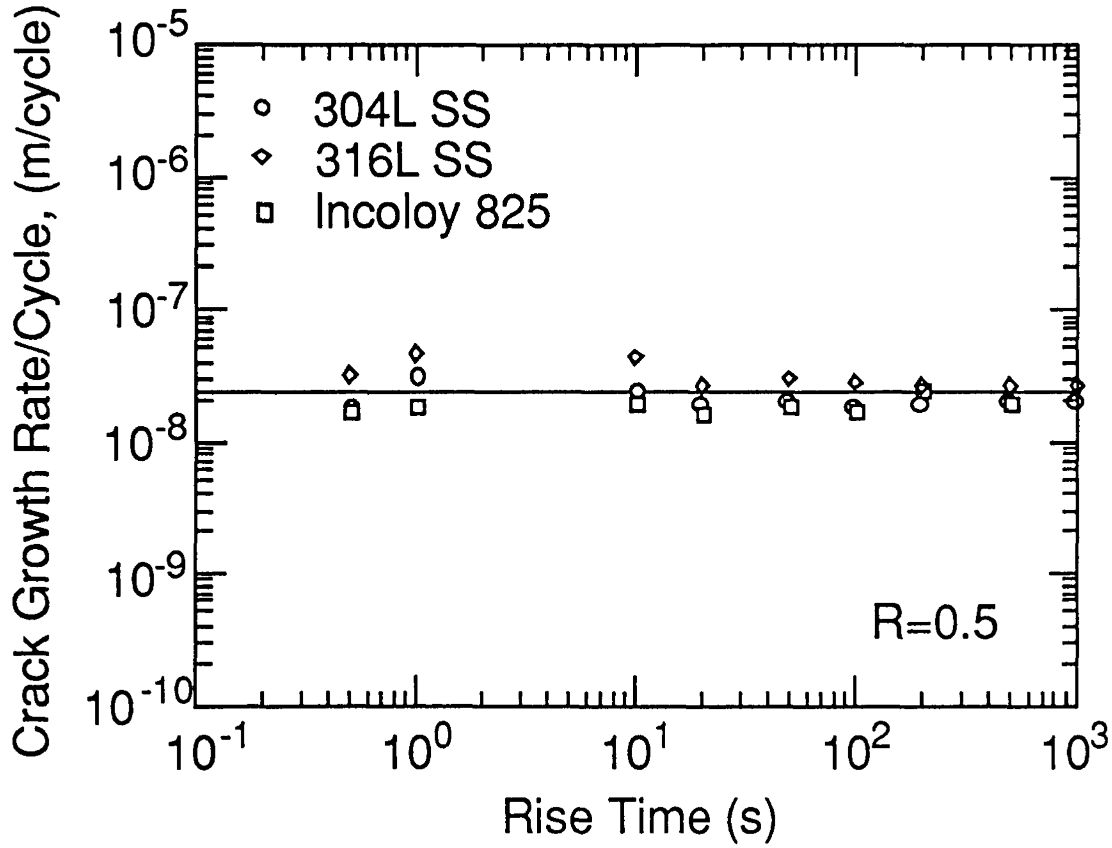
Observed Crack Growth Rates vs. Cyclic Frequency (R = 0.5)



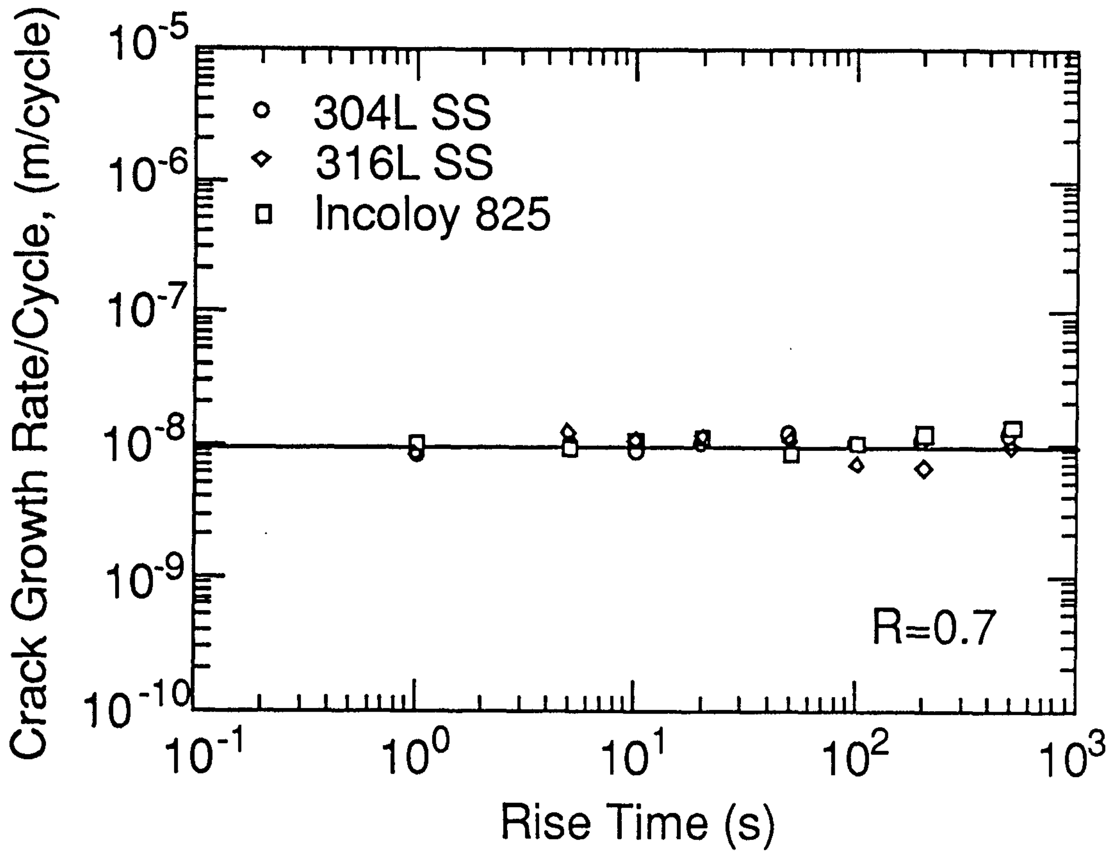
Observed Crack Growth Rates vs. Cyclic Frequency (R = 0.7)



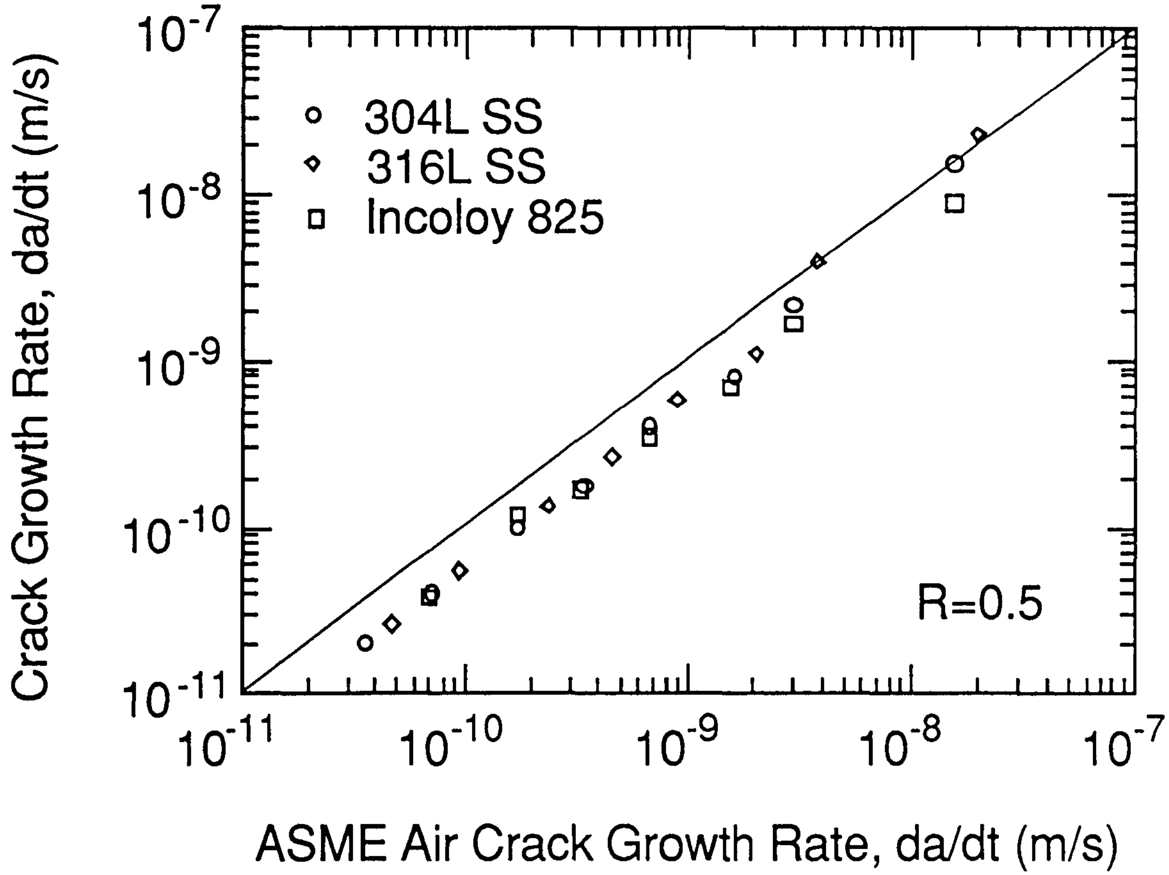
Observed Crack Growth Rates vs. Cyclic Rise Time (R = 0.5)



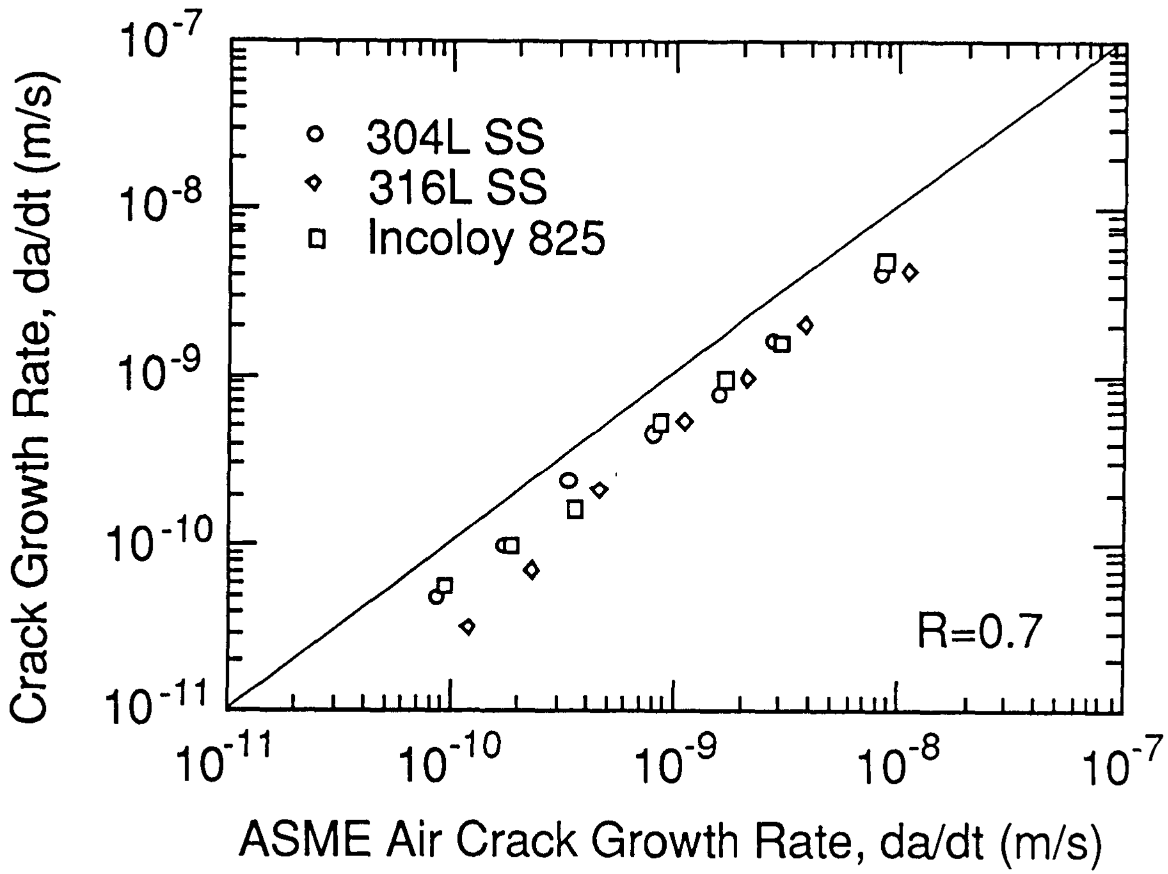
Observed Crack Growth Rates vs. Cyclic Rise Time (R = 0.7)



Observed Crack Growth Rates vs. ASME Section XI Rates for Austenitic Stainless Steels in Air (R = 0.5)



Observed Crack Growth Rates vs. ASME Section XI Rates for Austenitic Stainless Steels in Air (R = 0.7)



CONCLUSION

- No crack growth was detected for the Incoloy 825,Type 304L SS, and Type 316L SS tested at K = 25 MPa·$m^{1/2}$ and R = 0.9 - 1 for test times of 19,000 h. Based on the resolution of the measuring technique, the max. average crack growth rate under these conditions was ~8 x 10^{-13} m/s.

- No cyclic or rise–time-dependent environmental acceleration of crack growth was observable for the Incoloy 825,Type 304L SS, and Type 316L SS in the simulated J–13 well water at 93°C under the test conditions.

- Growth rates for R = 0.2-0.7 and maximum stress intensities of 26–40 MPa·$m^{1/2}$ agree with the current ASME Section XI correlation for austenitic stainless steel within a factor of 4.

- Crack growth rates data needed for different heats of alloys and for other materials conditions, i.e. welding and thermal aging etc.

Current Efforts (FY1994)

Alloys:	Incoloy 825, Type 304L, Type SS 316L SS Ti Grade 12, Hastelloy C-4, Hastelloy C-22
Materials Condition:	Mill Annealed / As-Received
Environment:	Simulated J-13

Additional Investigations Proposed

- Effects of Material Fabrication

  Heat variability, Welding, Heat treatments, Aging

- Galvanic Coupling

- Environmental Variability

  Compositional changes

  Dry-Wet condition