The Expansion of the Panama Canal

a Geotechnical Perspective

presentation to the

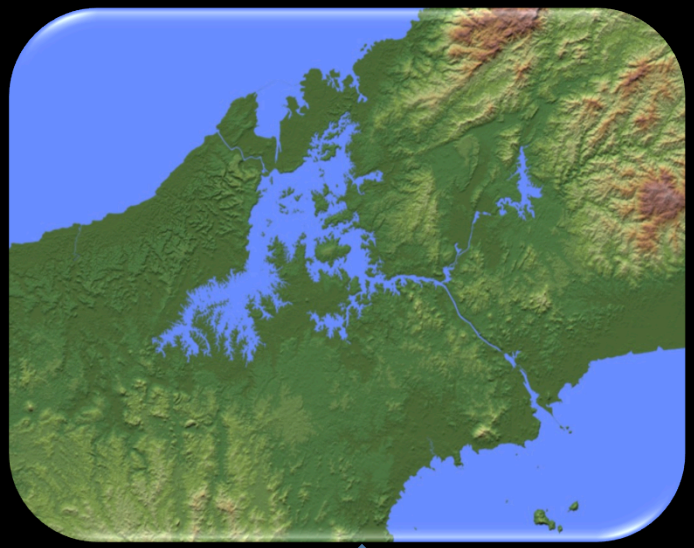
Purdue Geotechnical Society

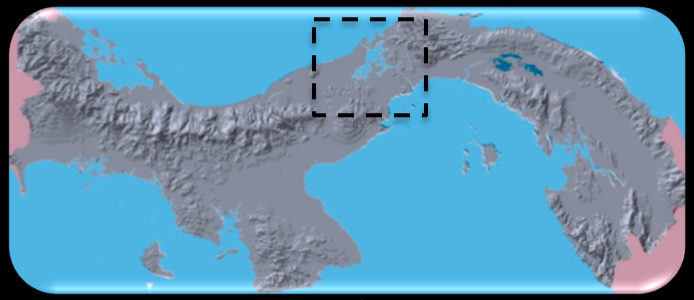
CANAL DE PANAMÁ

Luis D. Alfaro
Vicepresident of Engineering
Panama Canal Authority

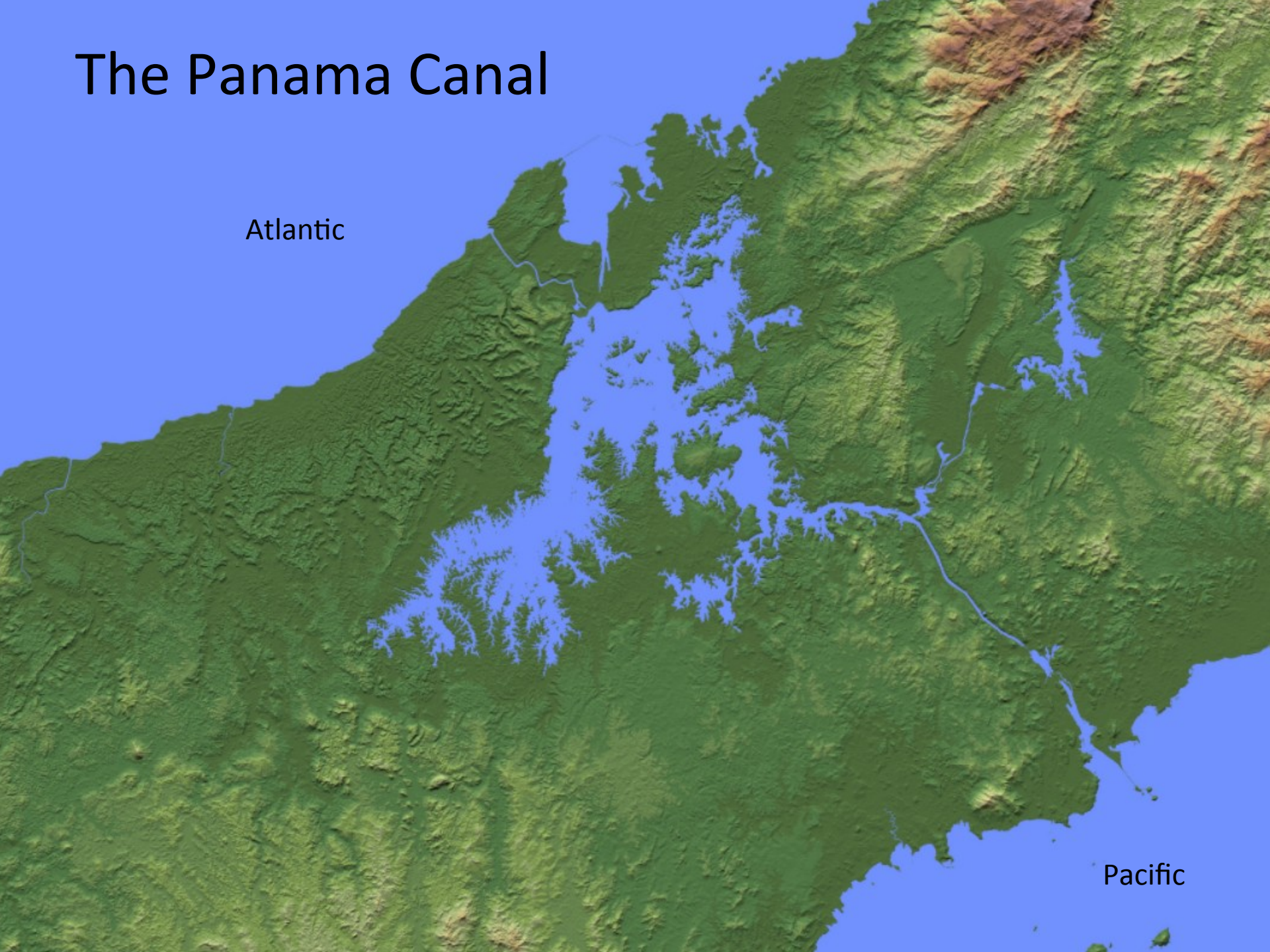
April 8, 2011

Panama

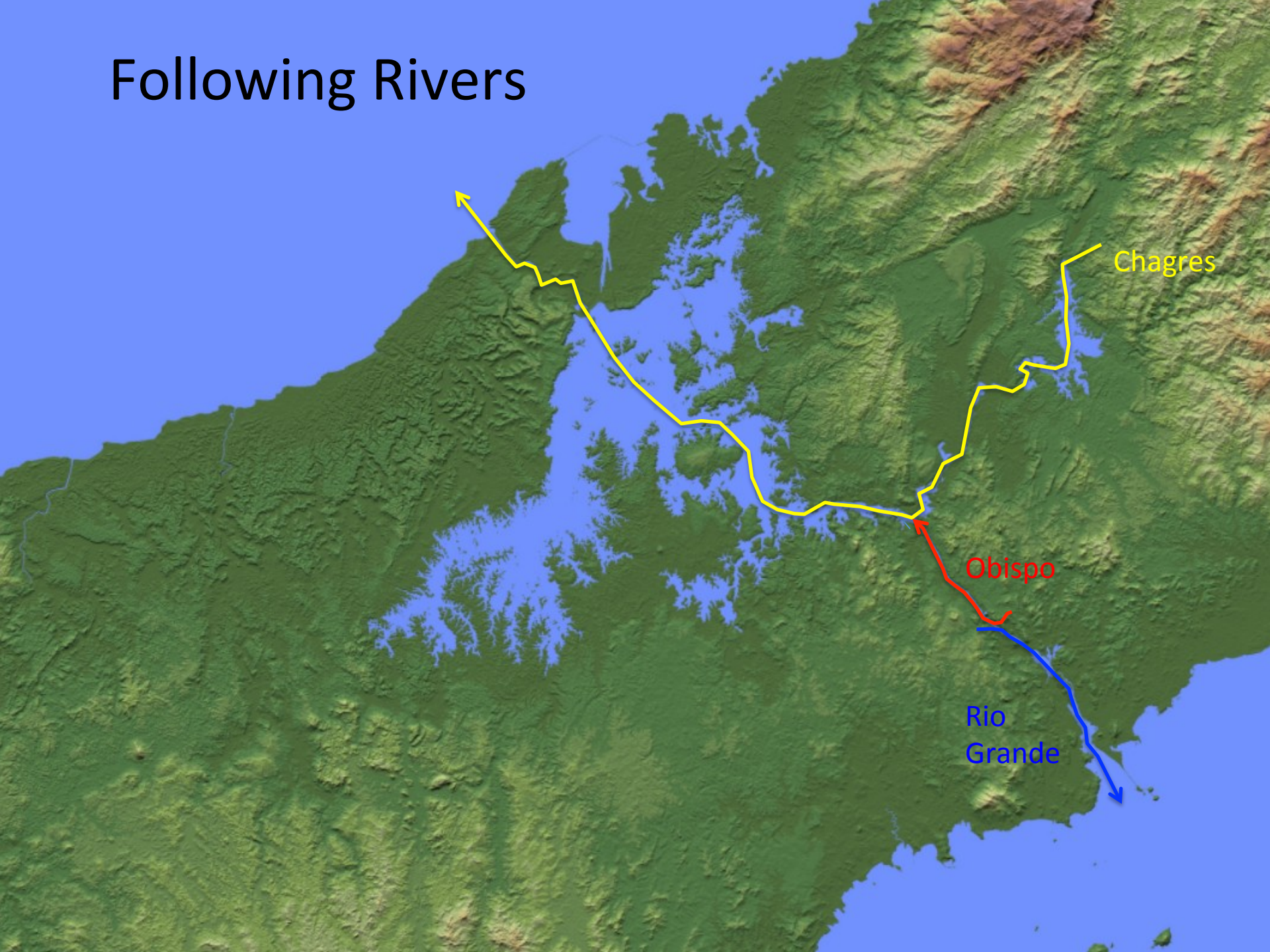




The Panama Canal

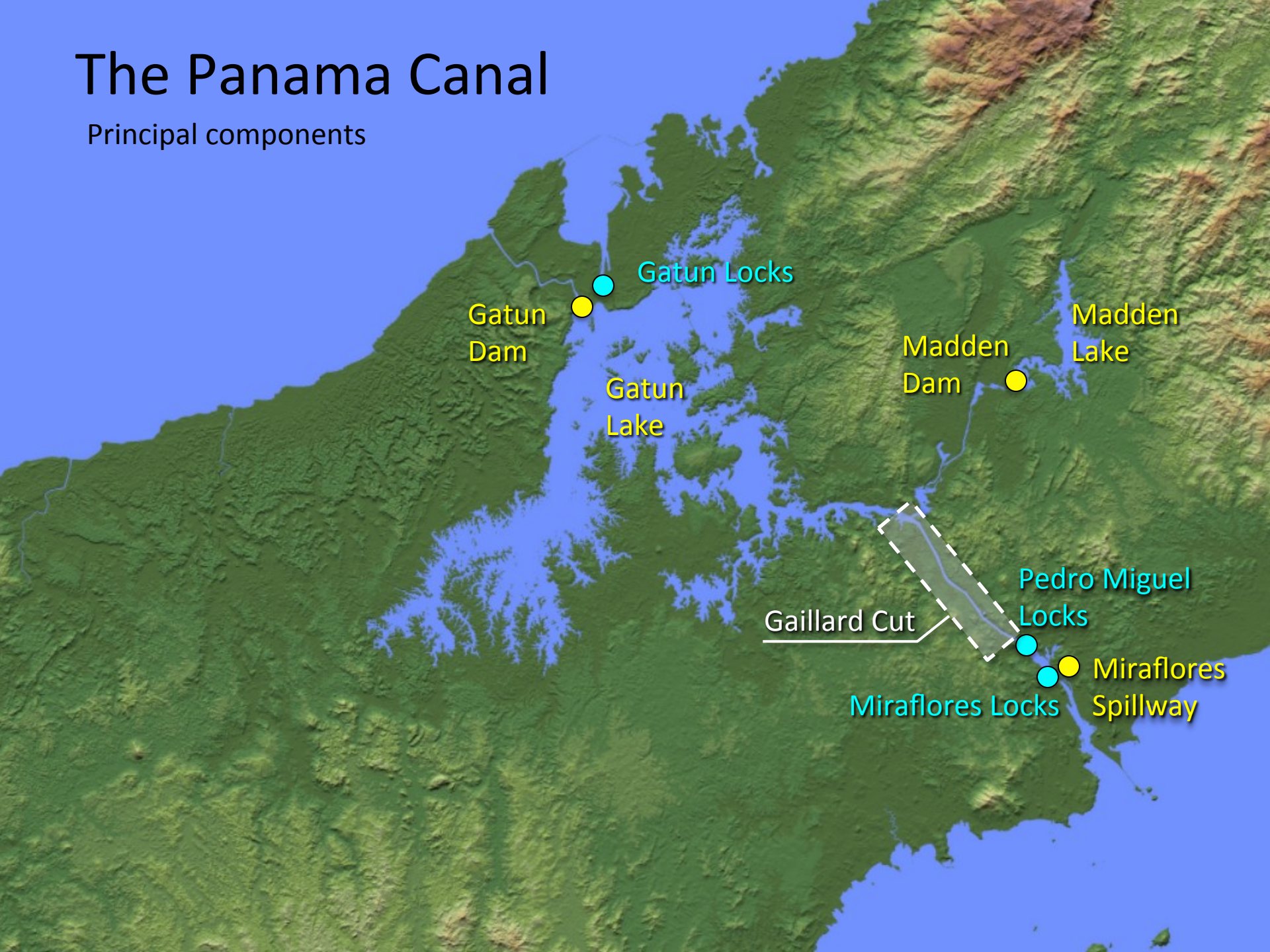


Following Rivers

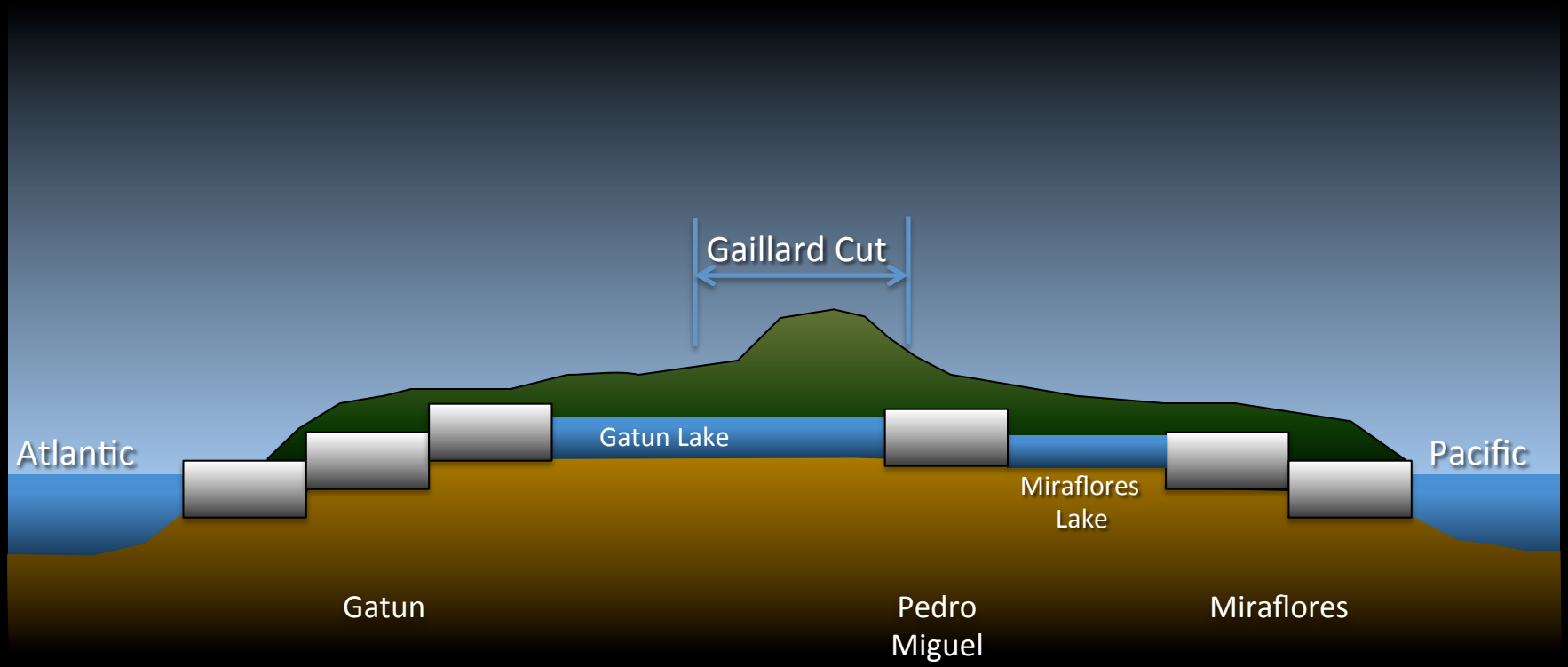


The Panama Canal

Principal components

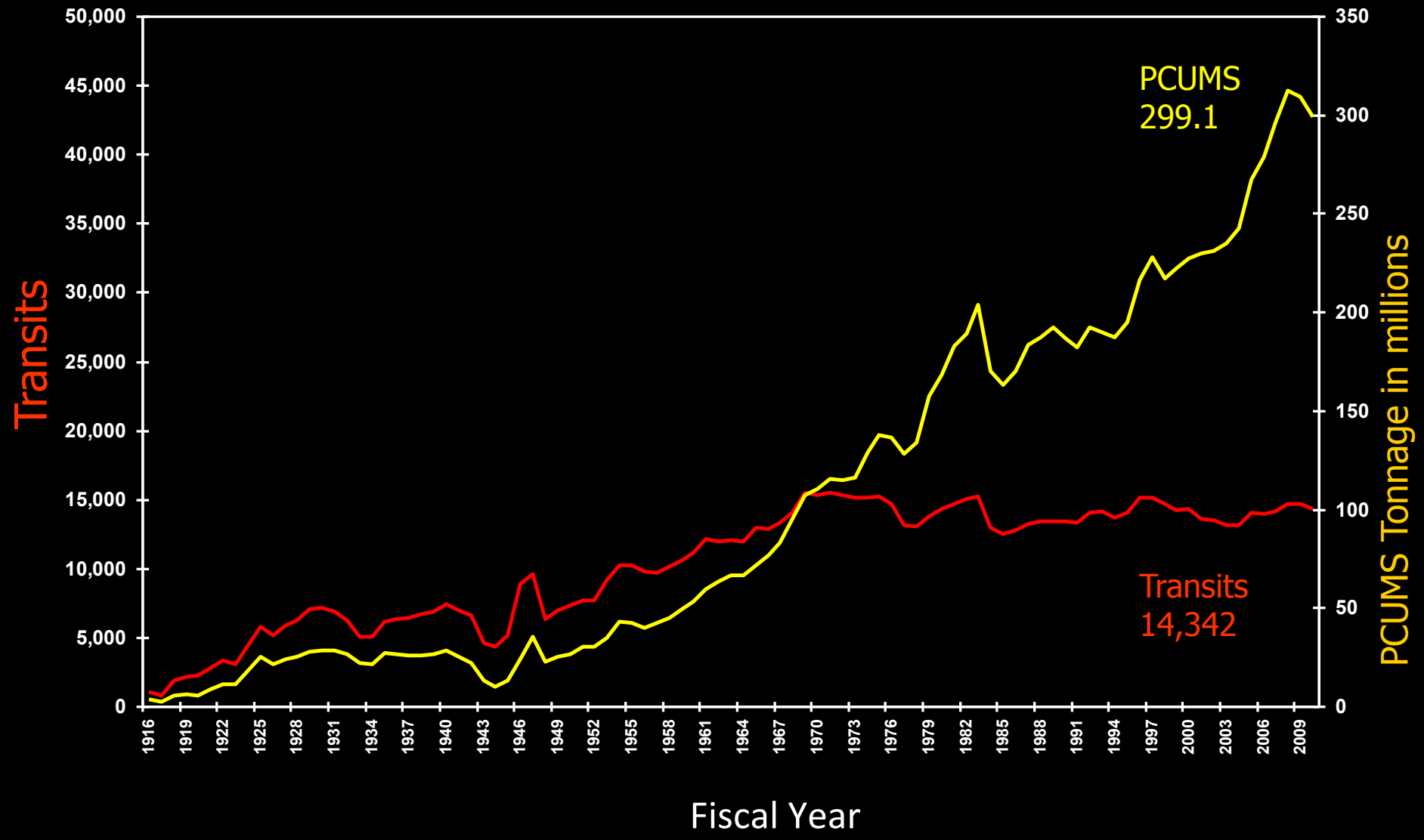


Longitudinal Profile

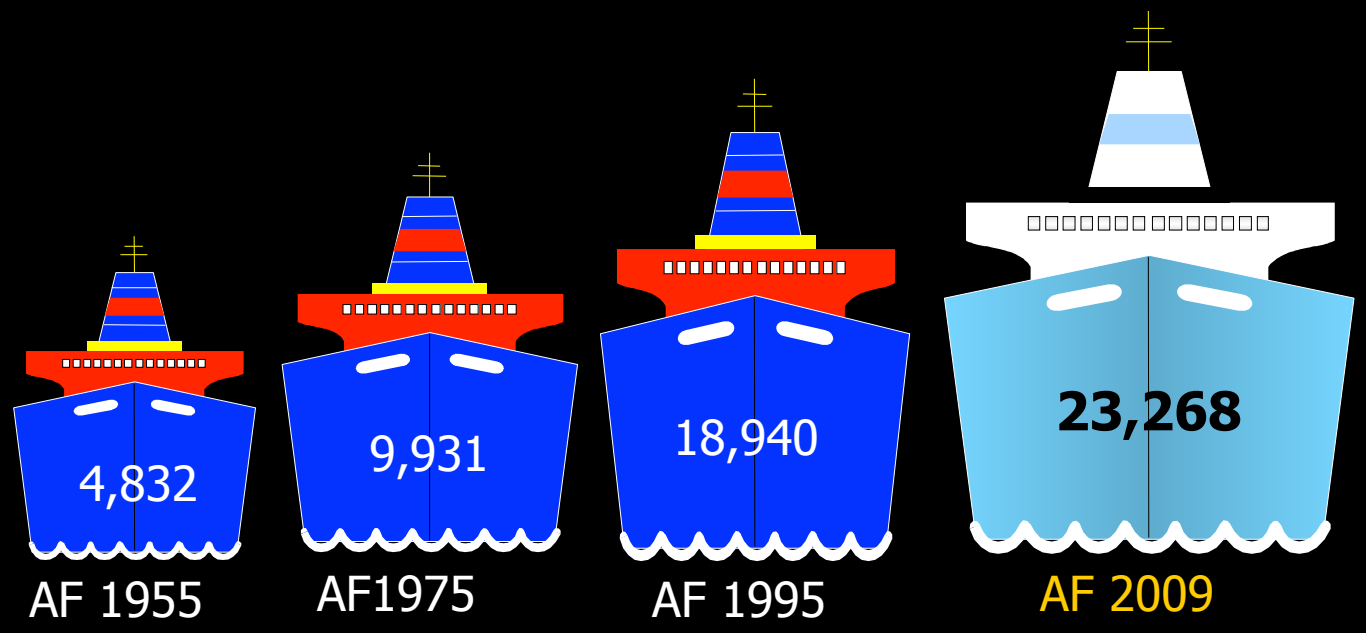


History of Panama Canal Traffic

FY 1915 – FY 2009

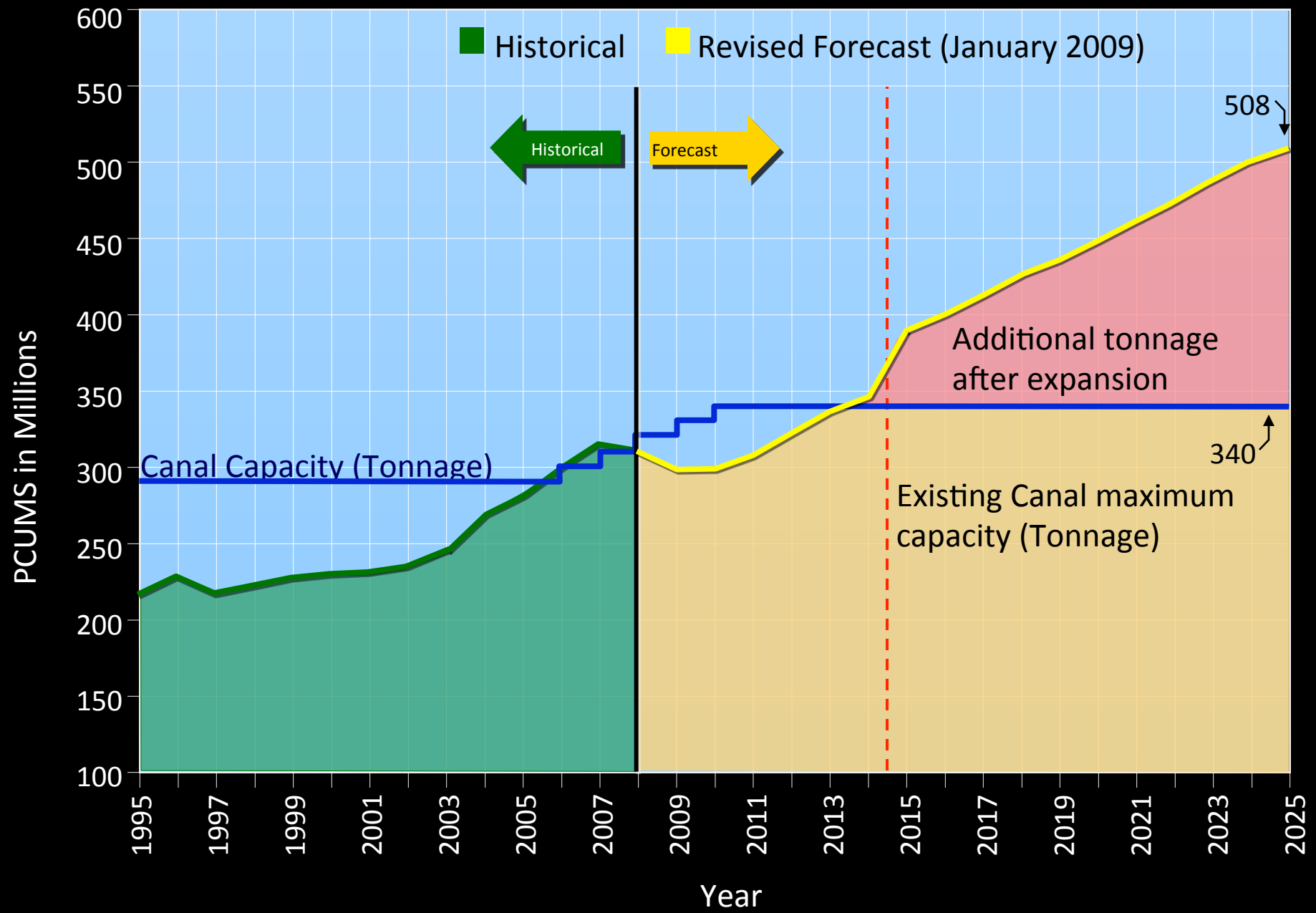


Growth in average ship size

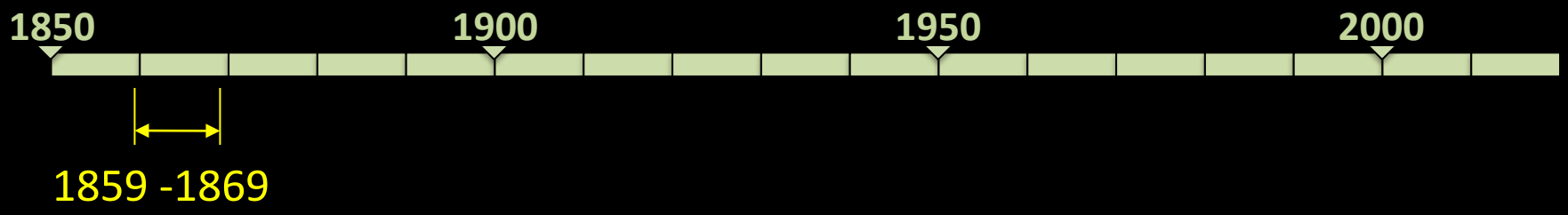


PCUMS Tonnage of Comercial Transits

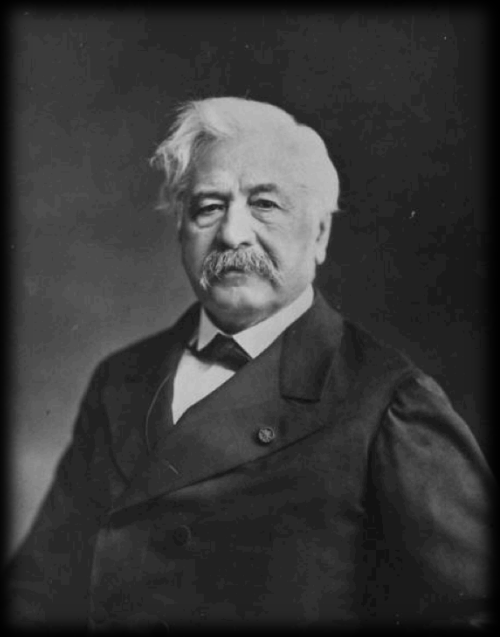
Demand for shipping



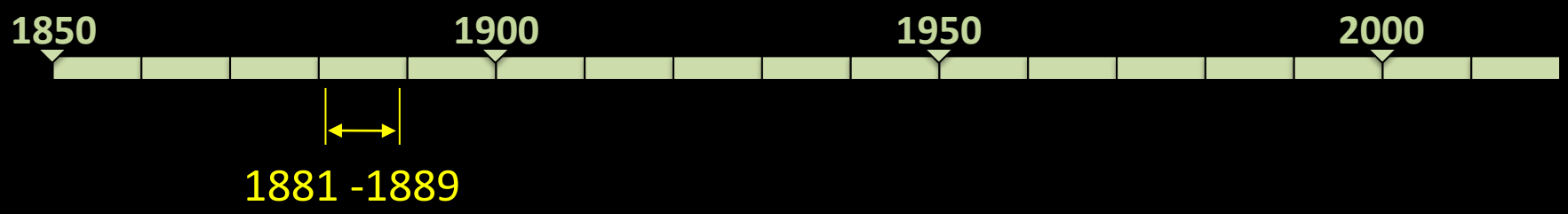
History of the Canal
and
and the impact of Geotechnical developments



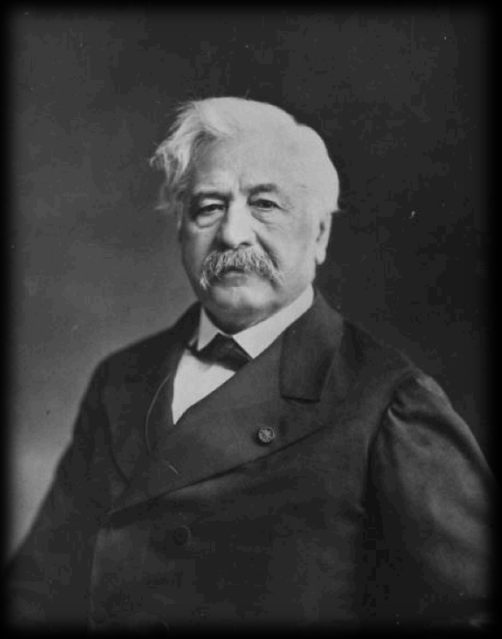
The Suez Canal



Ferdinand De Lesseps
(1805-1894)

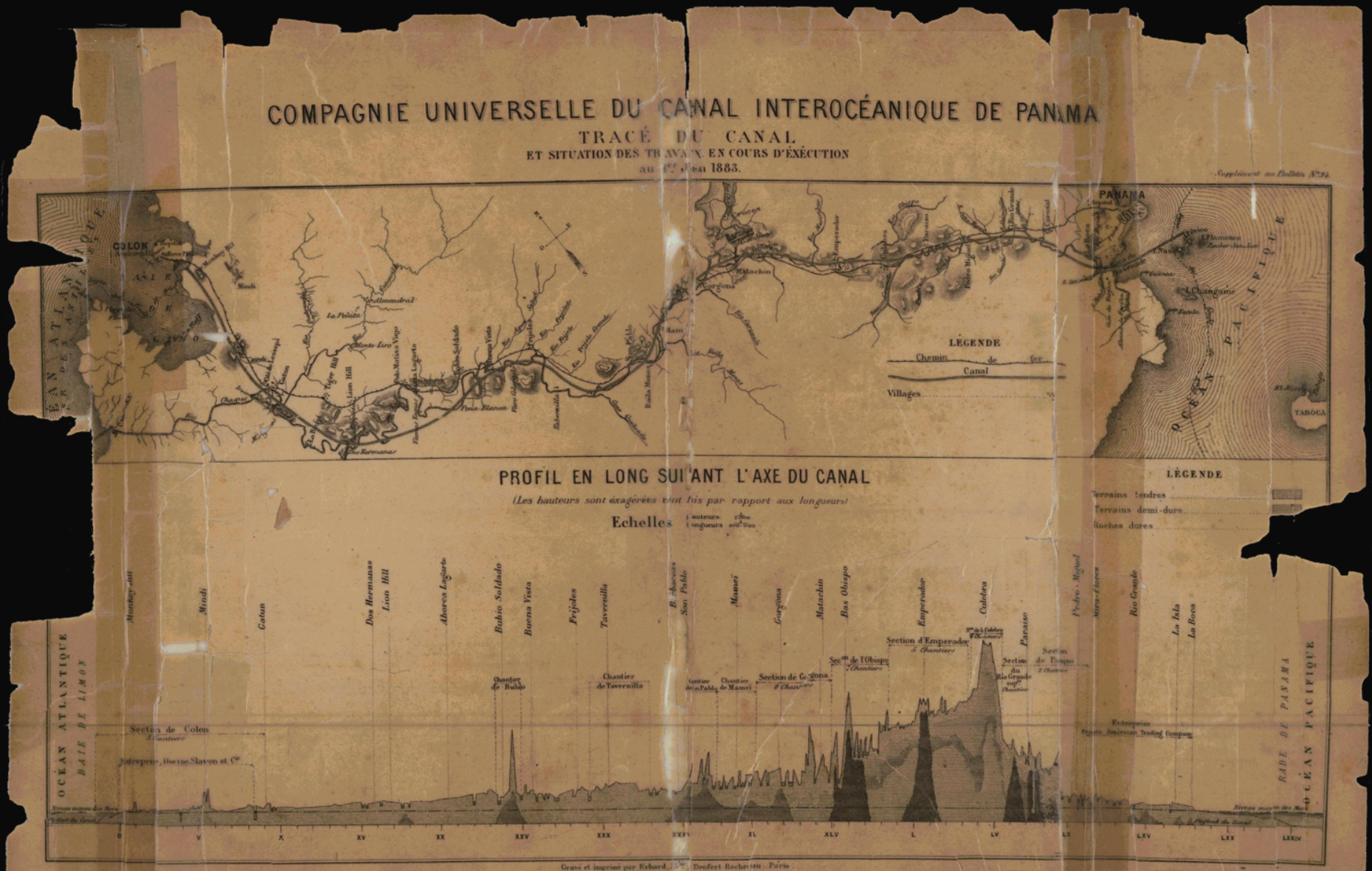


The French effort in Panama (23 Mm^3)



Ferdinand De Lesseps
(1805-1894)

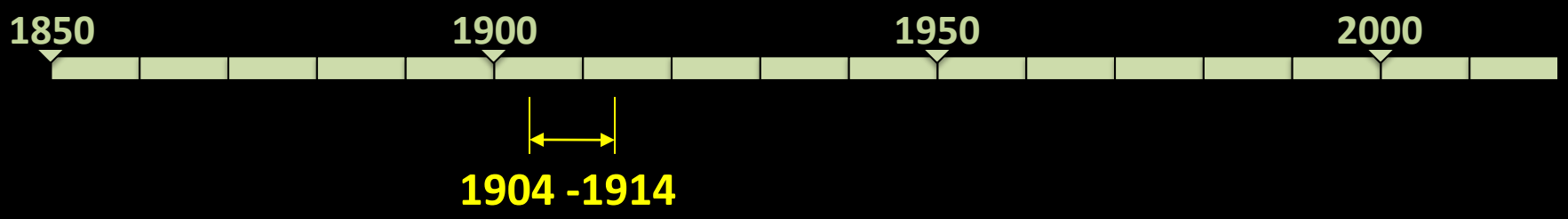
French plan (1883)



Excavation Volumes (Mm^3)

23

French effort

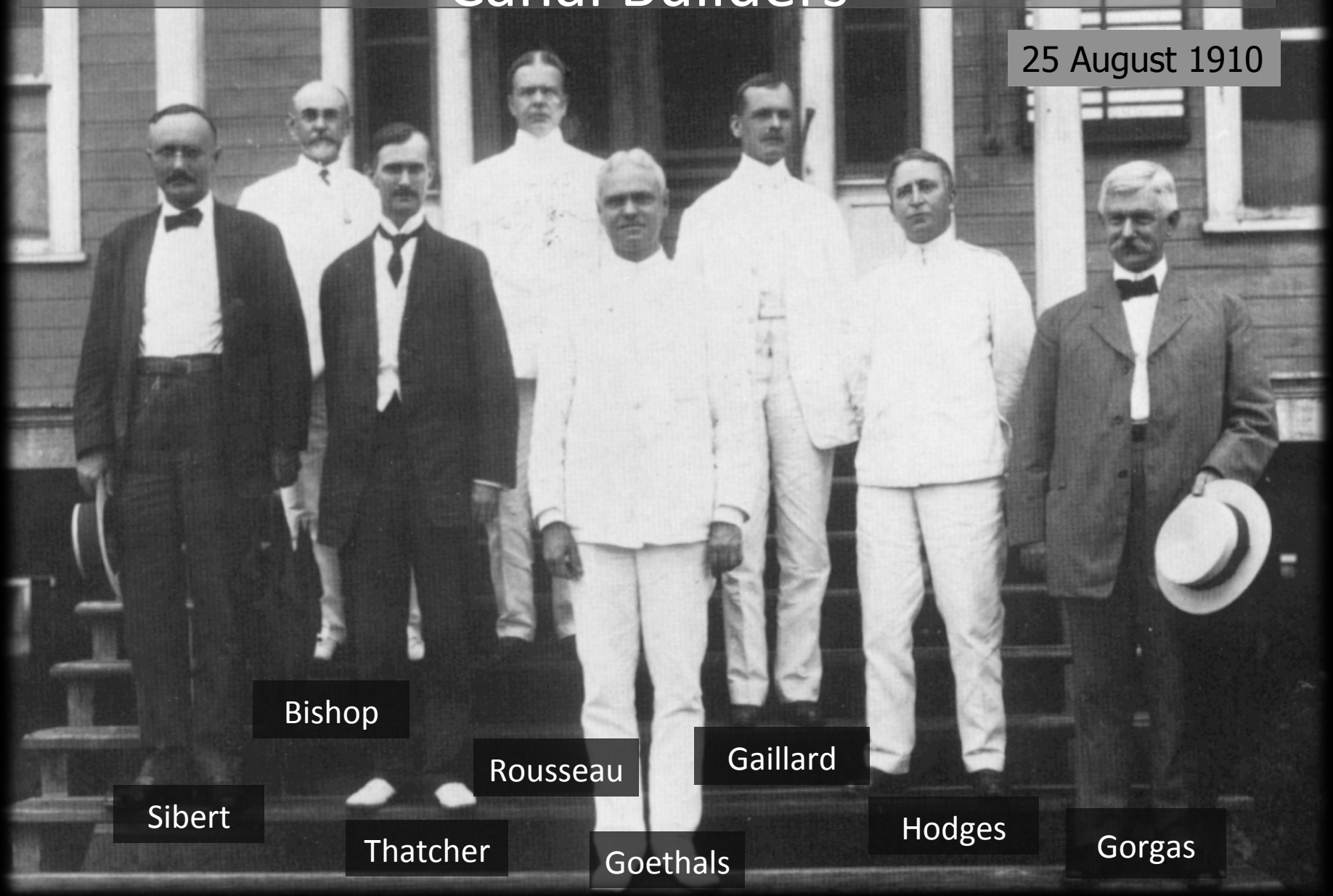


Col. George Goethals
(1858-1928)

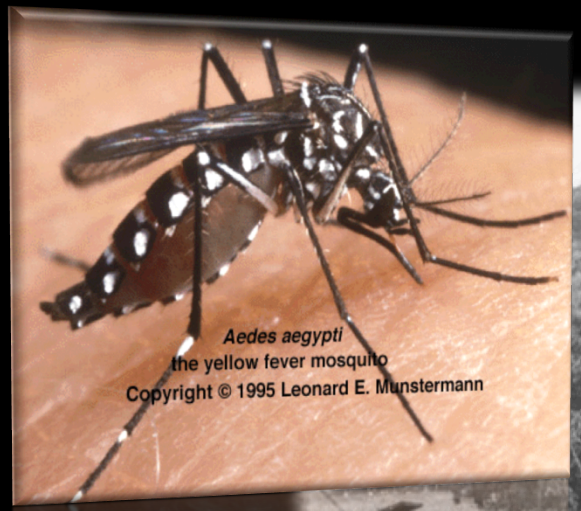
- Logistics
- Tropical disease
- Landslides

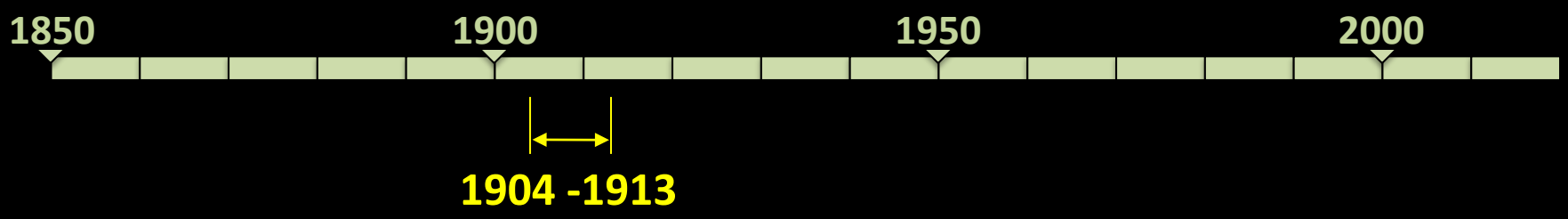
Canal Builders

25 August 1910



Yellow fever





Col. David DuBose Gaillard
(1859-1913)

In charge of excavations through the continental divide (Culebra Cut)

Completed the task, considering the extremely limited knowledge and tools at his disposal

February 10, 1911
East Culebra Slide

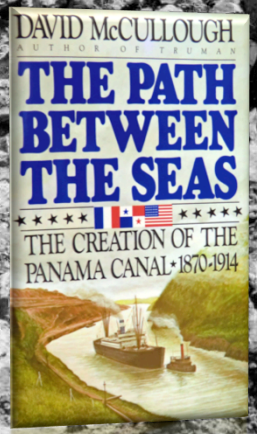
September 19, 1912
East Culebra Slide

February 2, 1913
East Cucaracha Slide

Excavation Methodology

February 7, 1913

East Cucaracha Slide



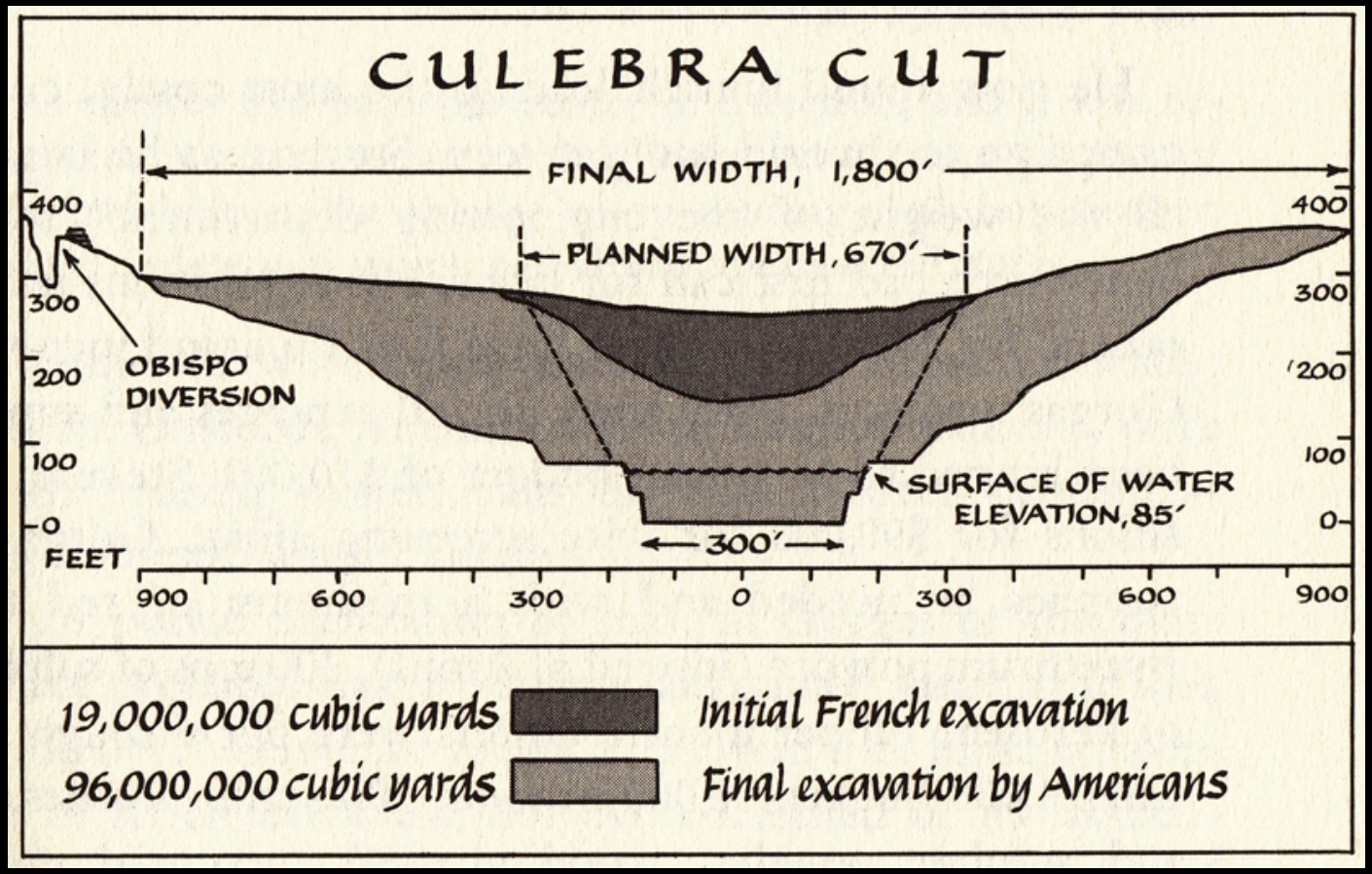
September 13, 1913

East Cucaracha Slide

May 29, 1913
East Cucaracha Slide

Original Design Excavations

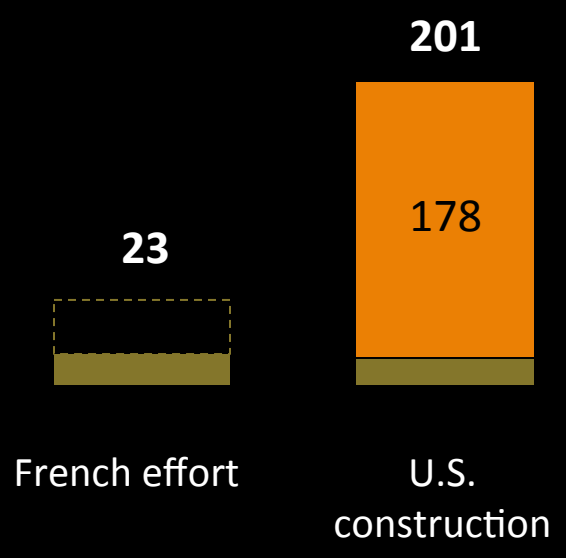
Reference: McCullough "The Path Between the Seas" (1977)



Steamship Ancon

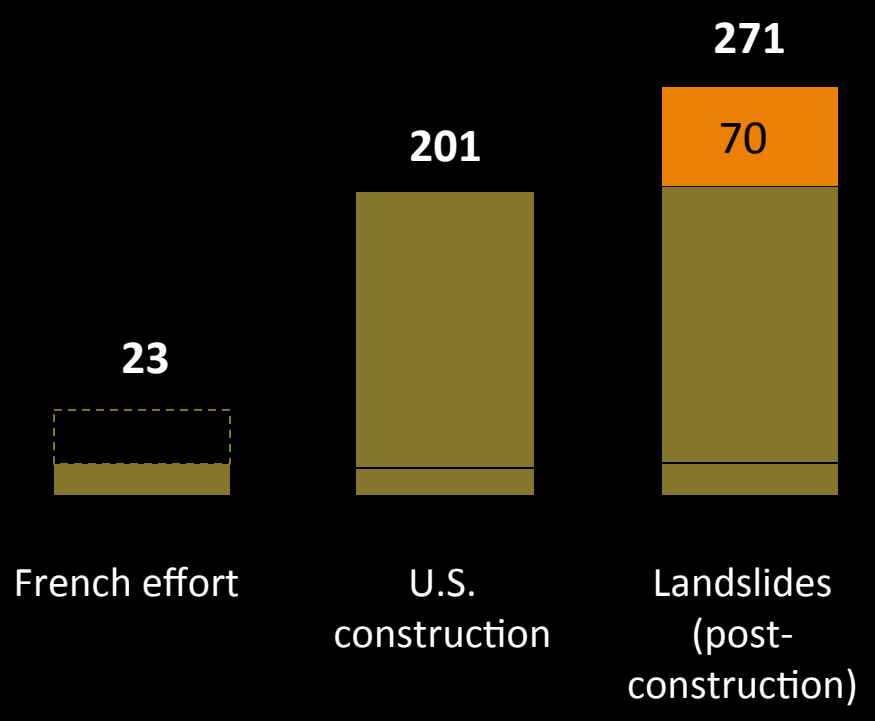
August 15, 1914

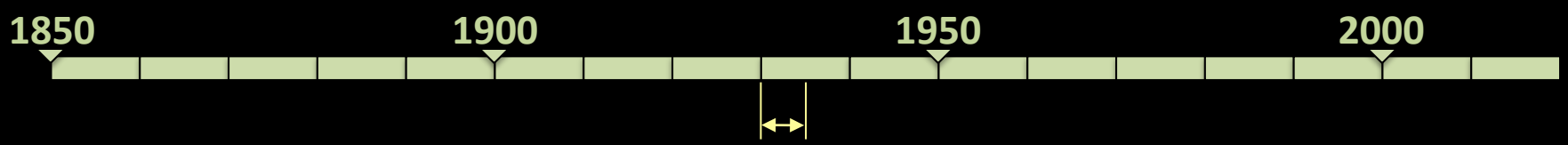
Excavation Volumes (Mm^3)



East & West Culebra slides (October 1915)

Excavation Volumes (Mm^3)





1930-1935

Construction of Madden Dam

1850 1900 1950 2000

1936

1850 1900 1950 2000

1936

Karl von Terzaghi
(1883-1963)

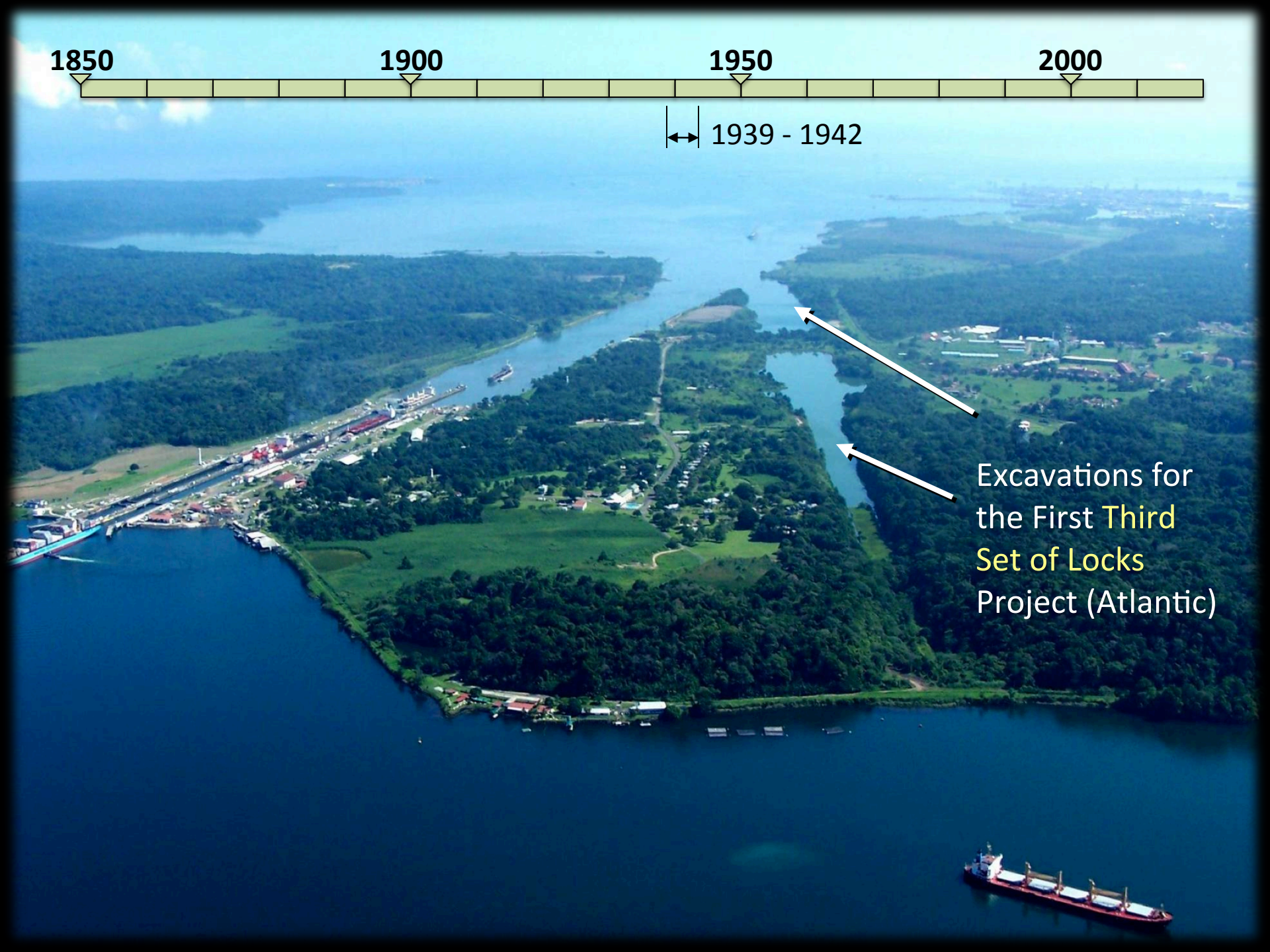
"…. the catastrophic descent of the slopes in the deepest cuts on the Panama Canal issued a warning the we were overstepping the limits of our ability to predict the consequences of our actions."

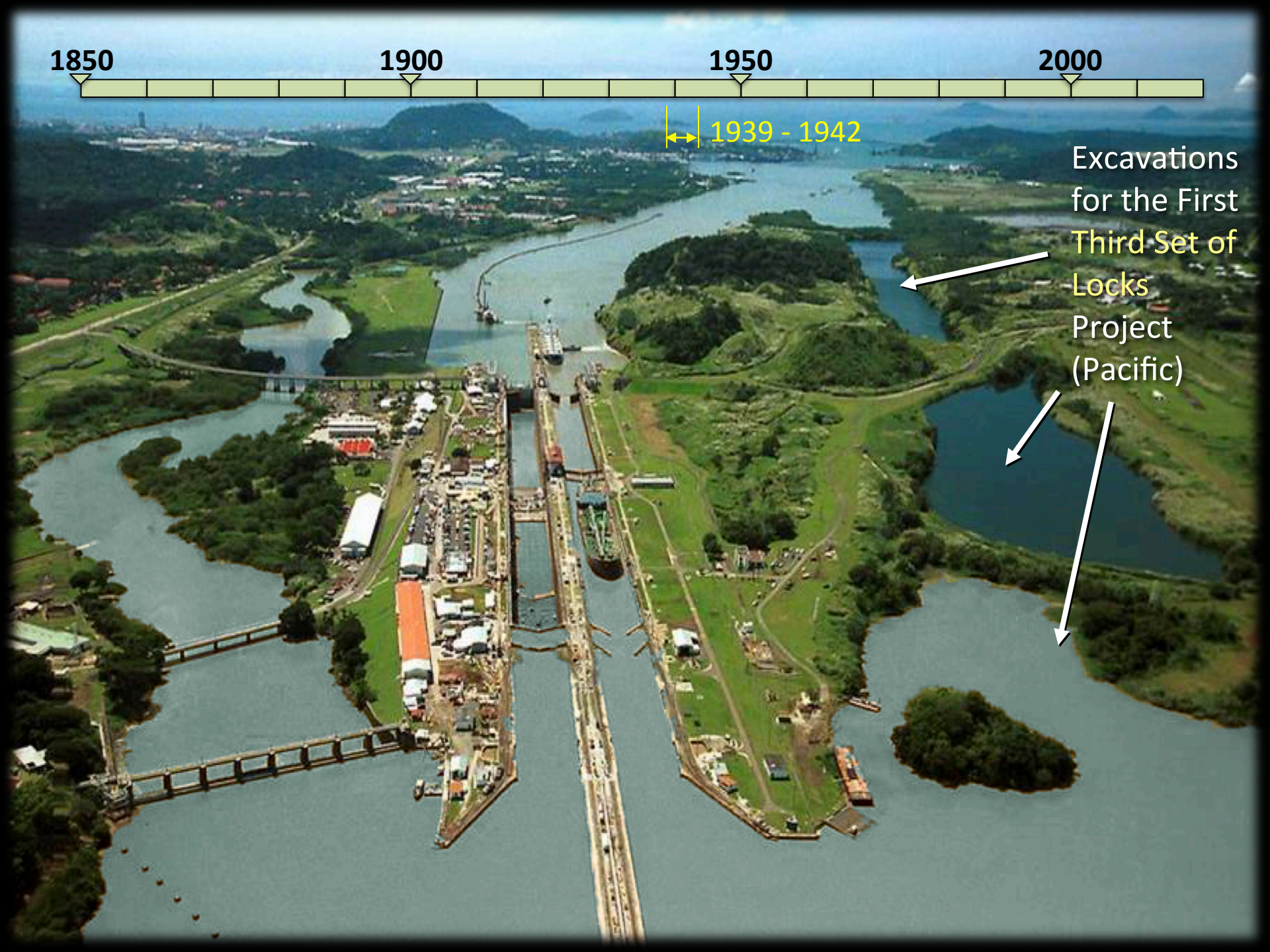
Presidential Address given at the first International Conference on Soil Mechanics and Foundation Engineering, Cambridge Massachusetts, June 1936

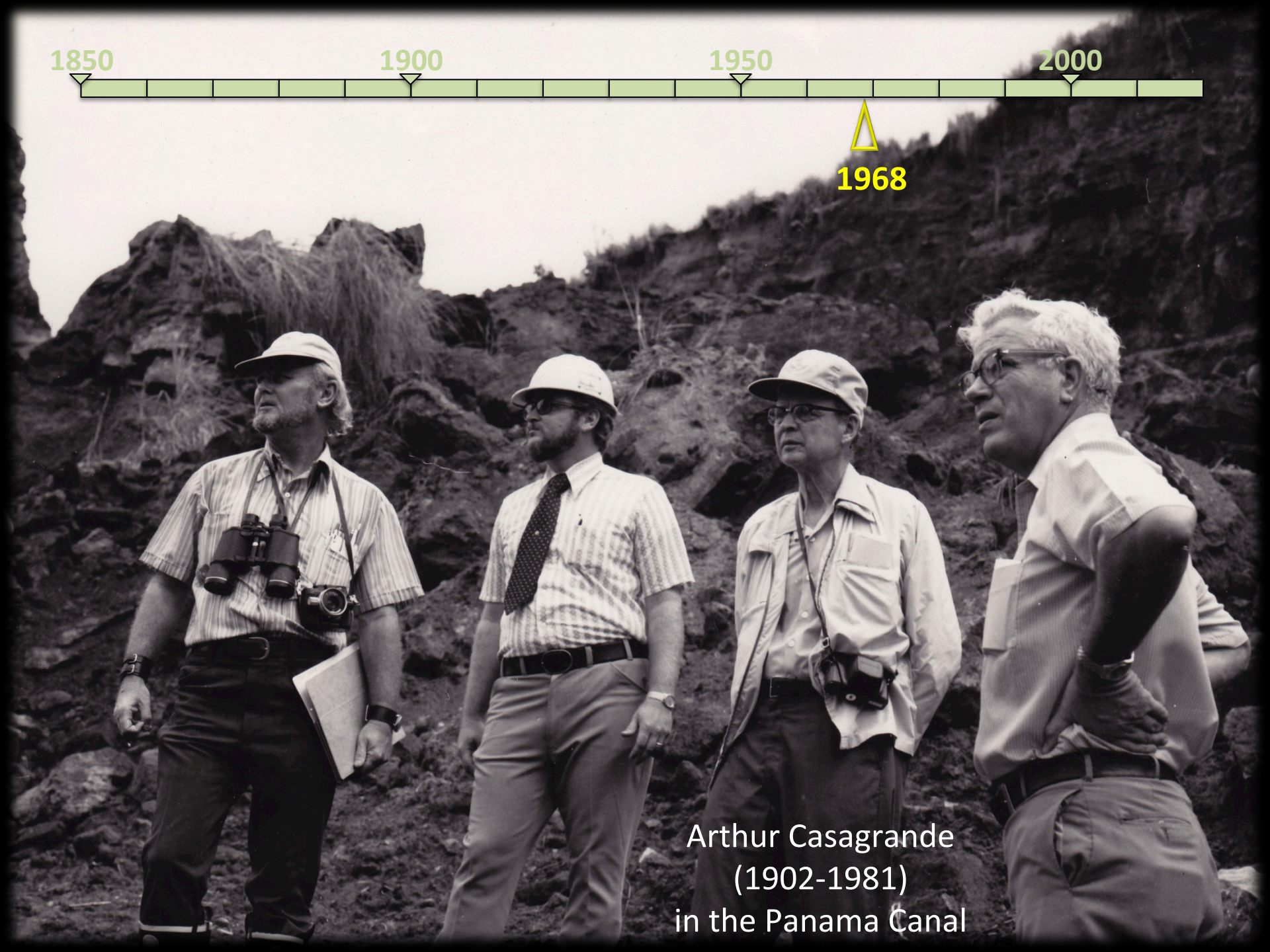
1850 1900 1950 2000

1939 - 1942

9-D-12 (12) The Panama Canal - Third Locks Project - Dry Excavation.
Gatun - March 1941.

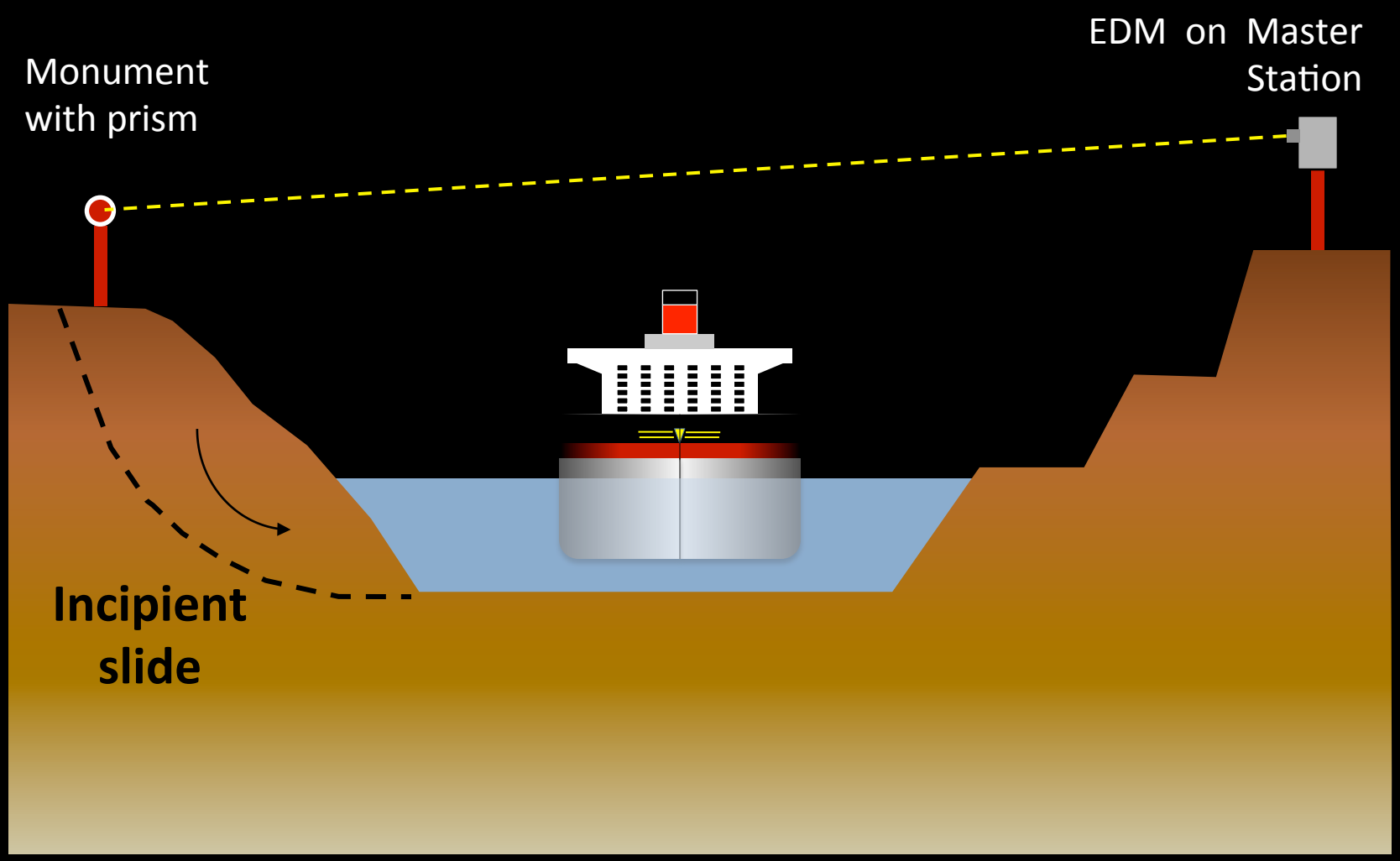

1850
1900
1950
2000
1939 - 1942
Excavations for the First Third Set of Locks Project (Atlantic)


1850
1900
1950
2000
1939 - 1942
Excavations for the First Third Set of Locks Project (Pacific)

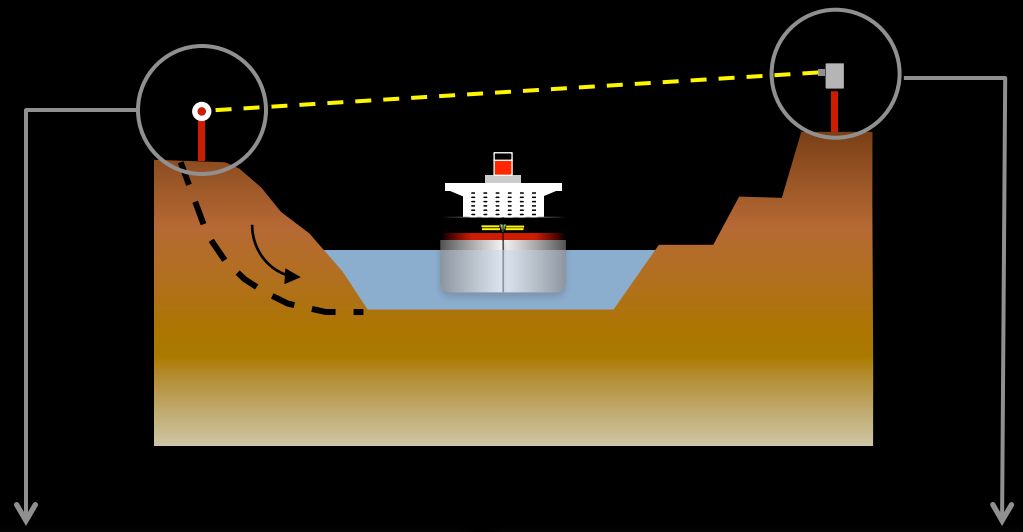


Arthur Casagrande
(1902-1981)
in the Panama Canal

Modern Landslide Control Program



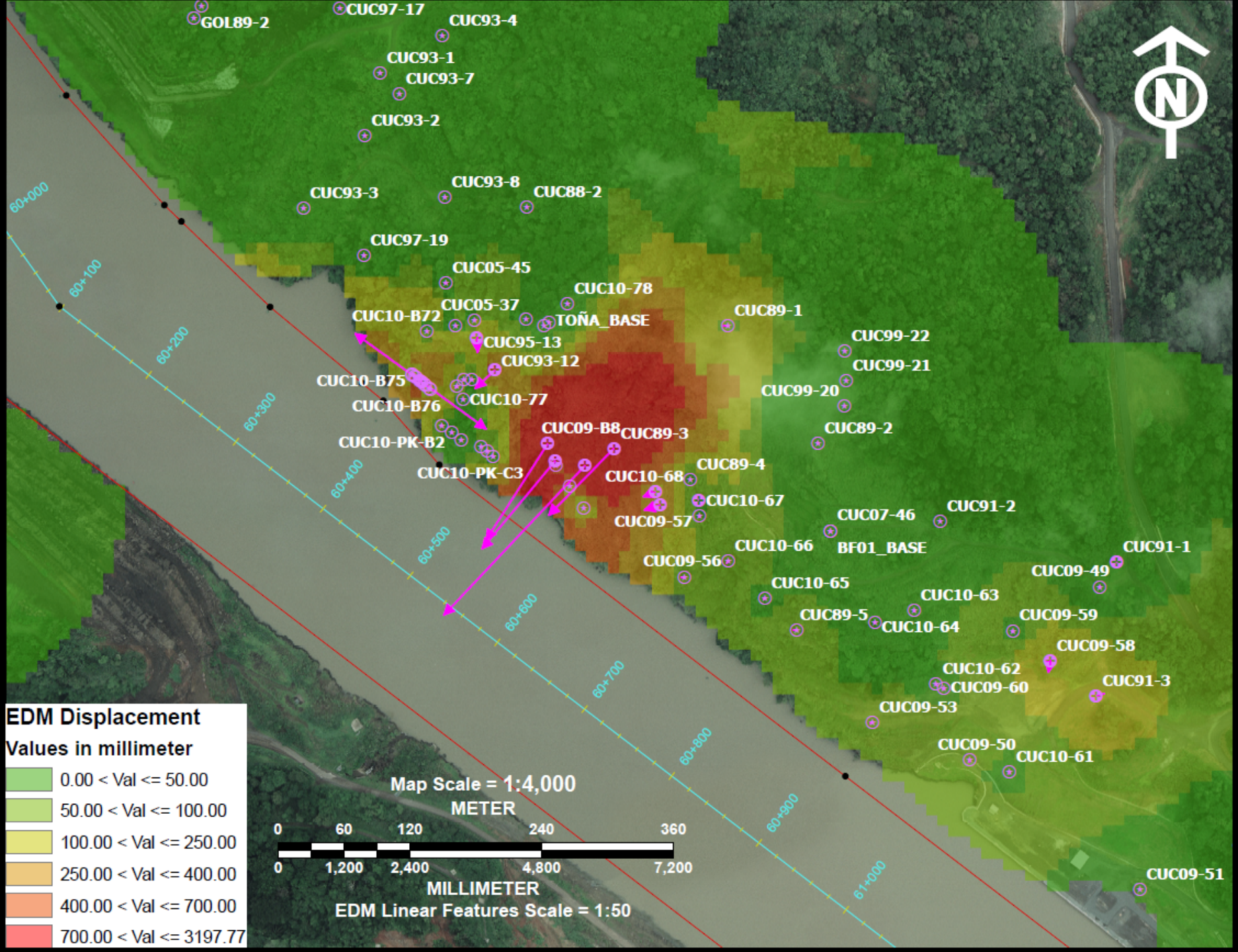
Modern Landslide Control Program



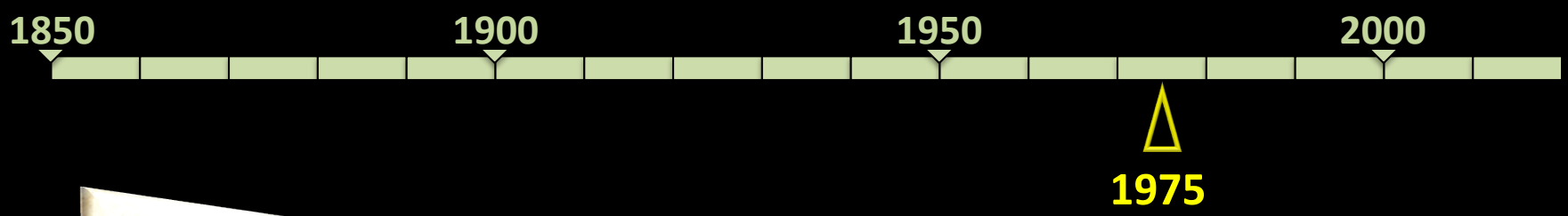
Threshold Values

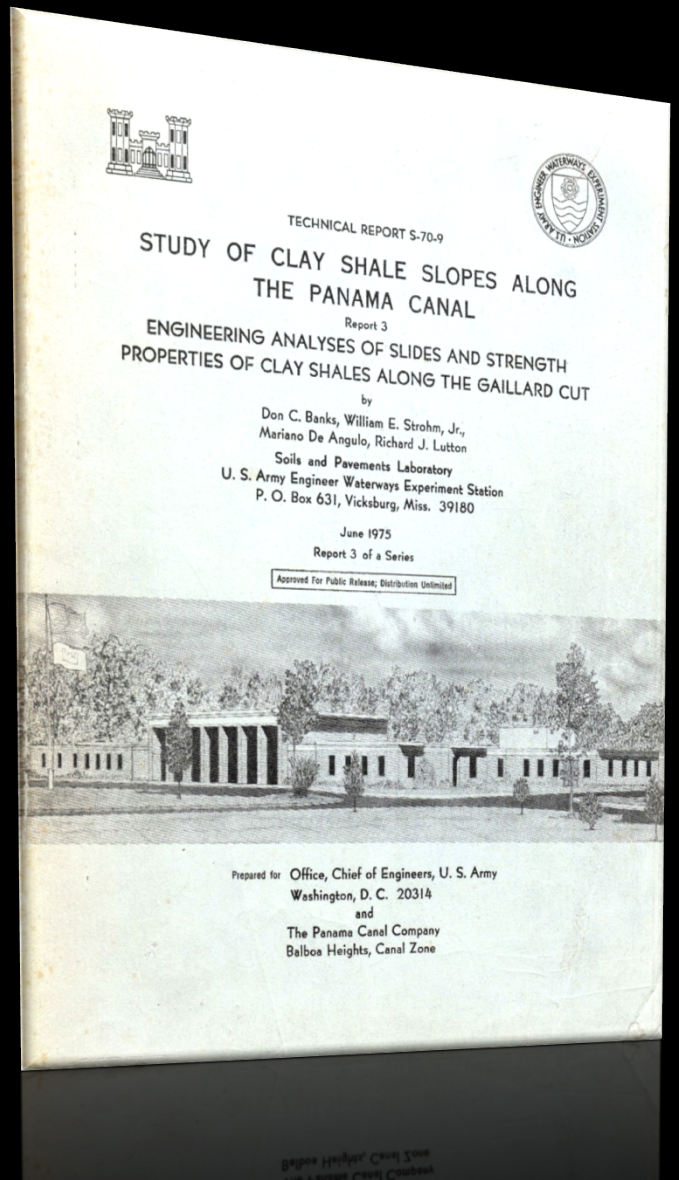
> 30mm / month

> 100mm / year


GOL89-2
CUC97-17
CUC93-4
CUC93-1
CUC93-7
CUC93-2
CUC93-3
CUC93-8
CUC88-2
CUC97-19
CUC05-45
CUC10-78
CUC05-37
CUC10-B72
TOÑA_BASE
CUC89-1
CUC95-13
CUC93-12
CUC99-22
CUC99-21
CUC10-B75
CUC10-77
CUC99-20
CUC10-B76
CUC09-B8
CUC89-3
CUC89-2
CUC10-PK-B2
CUC10-PK-C3
CUC10-68
CUC89-4
CUC10-67
CUC09-57
CUC07-46
CUC91-2
CUC10-66
BF01_BASE
CUC91-1
CUC09-56
CUC09-49
CUC10-65
CUC10-63
CUC89-5
CUC10-64
CUC09-59
CUC09-58
CUC10-62
CUC09-60
CUC91-3
CUC09-53
CUC09-50
CUC10-61
CUC09-51
60+000
60+100
60+200
60+300
60+400
60+500
60+600
60+700
60+800
60+900
61+000
N
EDM Displacement
Values in millimeter
0.00 < Val <= 50.00
50.00 < Val <= 100.00
100.00 < Val <= 250.00
250.00 < Val <= 400.00
400.00 < Val <= 700.00
700.00 < Val <= 3197.77
Map Scale = 1:4,000
METER
0 60 120 240 360
0 1,200 2,400 4,800 7,200
MILLIMETER
EDM Linear Features Scale = 1:50

Sta. 1925 East Culebra Slide





TECHNICAL REPORT S-70-9

STUDY OF CLAY SHALE SLOPES ALONG THE PANAMA CANAL

Report 3

ENGINEERING ANALYSES OF SLIDES AND STRENGTH PROPERTIES OF CLAY SHALES ALONG THE GAILLARD CUT

by

Don C. Banks, William E. Strohm, Jr., Mariano De Angulo, Richard J. Lutton

Soils and Pavements Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

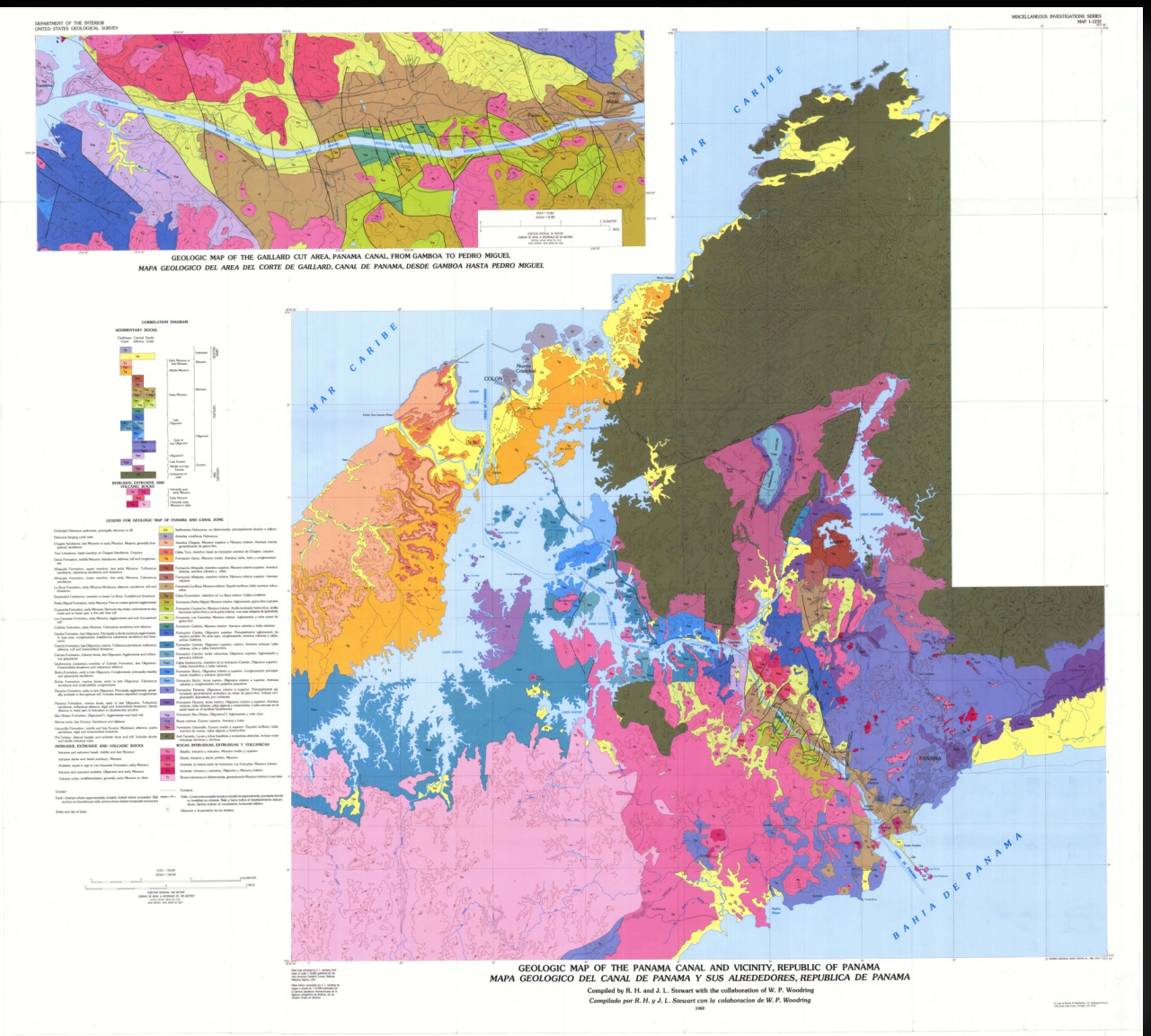
June 1975

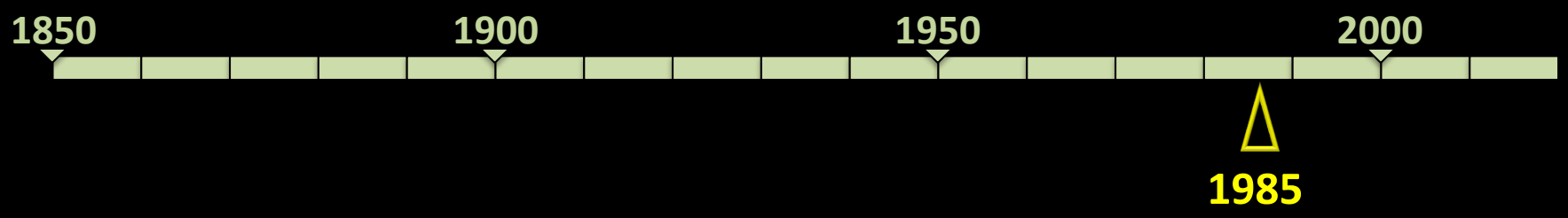
Report 3 of a Series

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314
and
The Panama Canal Company
Balboa Heights, Canal Zone

USACE Report S-70-9


1850
1900
1950
2000
Bob Stewart
Jay Stewart
USGS map (1980)
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
MISCELLANEOUS INVESTIGATIONS SERIES
GEOLOGIC MAP OF THE GAILLARD CUT AREA, PANAMA CANAL, FROM GAMBOA TO PEDRO MIGUEL
MAPA GEOLOGICO DEL AREA DEL CORTE DE GAILLARD, CANAL DE PANAMA, DESDE GAMBOA HASTA PEDRO MIGUEL
CORRELATION DIAGRAM
LEGEND FOR GEOLOGIC MAP OF PANAMA AND CANAL ZONE
MAR CARIBE
COLON
PANAMA
BAHIA DE PANAMA
GEOLOGIC MAP OF THE PANAMA CANAL AND VICINITY, REPUBLIC OF PANAMA
MAPA GEOLOGICO DEL CANAL DE PANAMA Y SUS ALREDEDORES, REPUBLICA DE PANAMA
Compiled by R. H. and J. L. Stewart with the collaboration of W. P. Woodring
Compilado por R. H. y J. L. Stewart con la colaboracion de W. P. Woodring
1980



Dr. Evert Hoek in the Panama Canal
1985

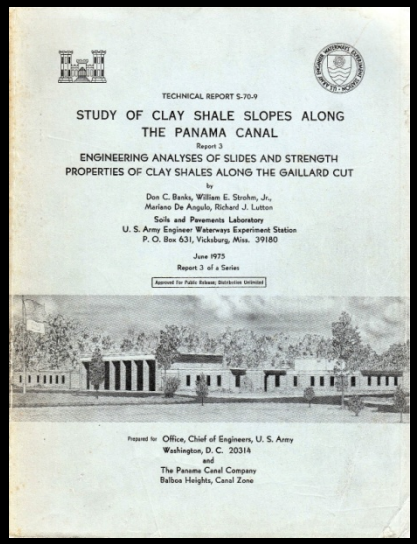
Shear strength characterization for weak rocks

Hoek-Brown envelope

$$\tau = (\cot \phi_i' - \cos \phi_i')\, m\, \sigma_c / 8$$

$$\phi_i' = \arctan[4h\cos^2\{30+(1/3)\arcsin h^{-3/2}\} -1]^{-1/2}$$

$$h = 1 + 16(m\sigma' + s\,\sigma_c)/(3m^2\,\sigma_c)$$



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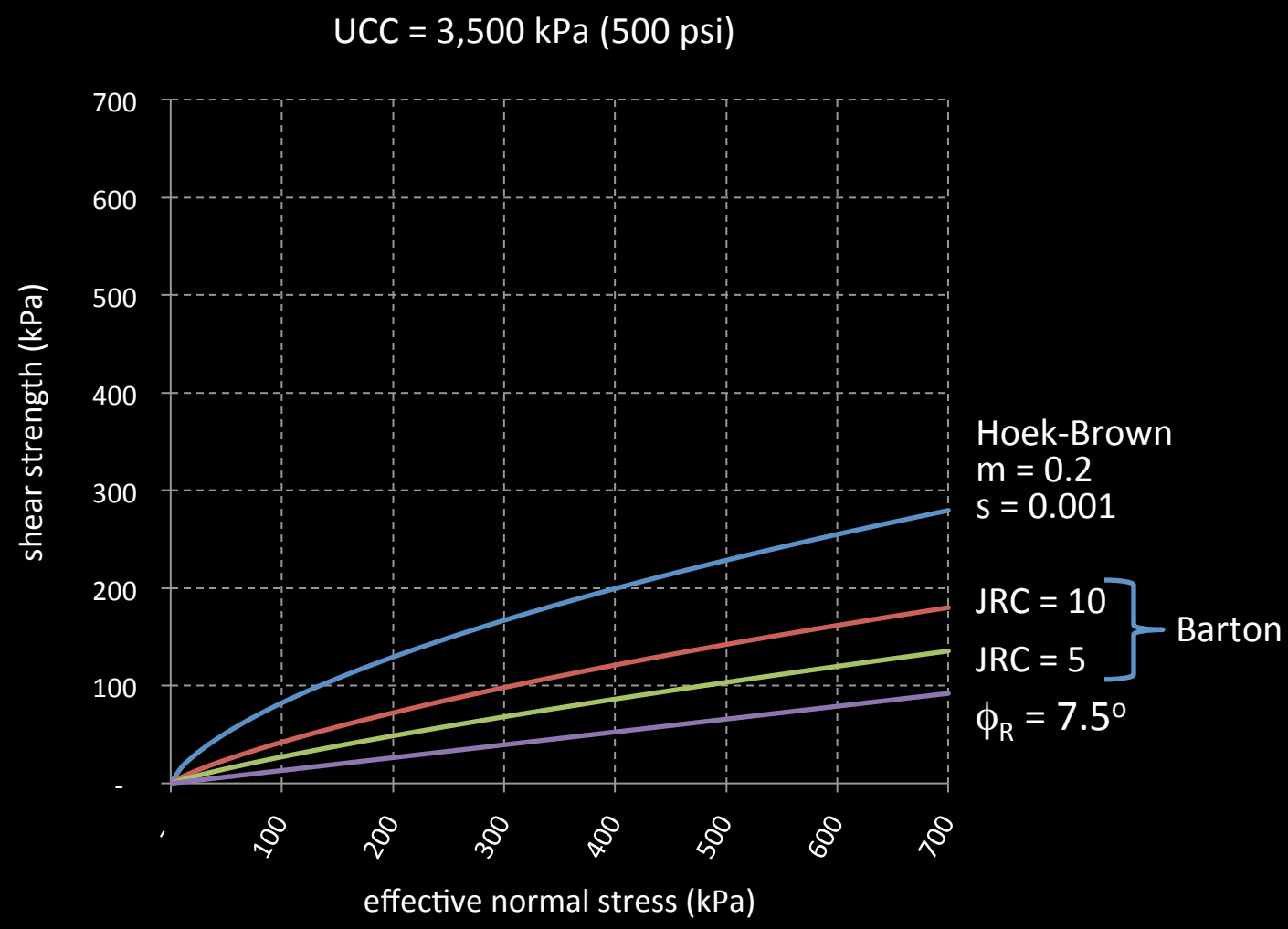
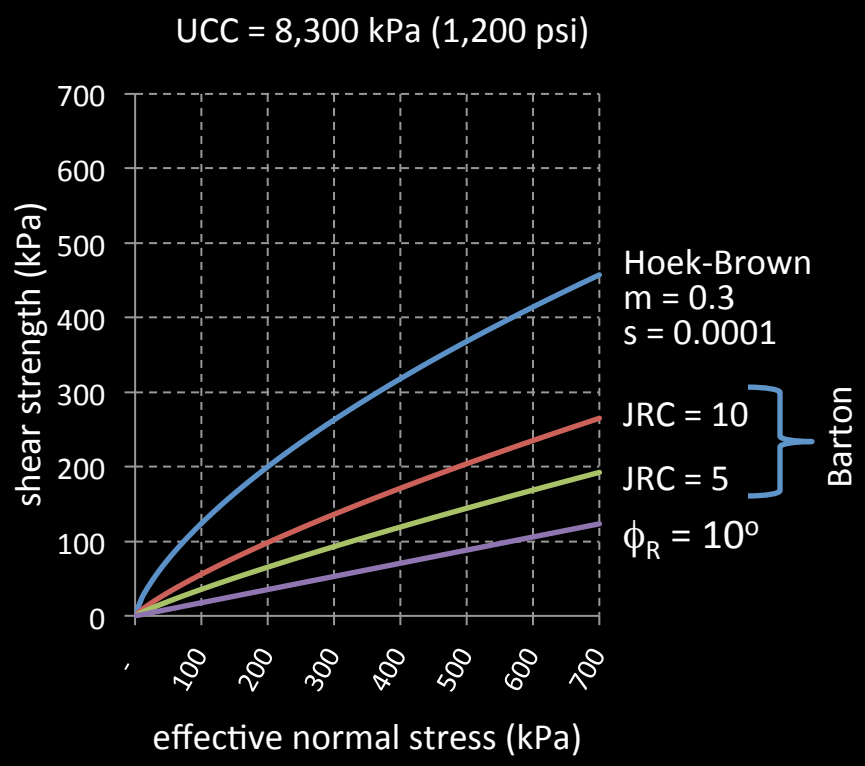
Strength Envelopes for weak tuffs

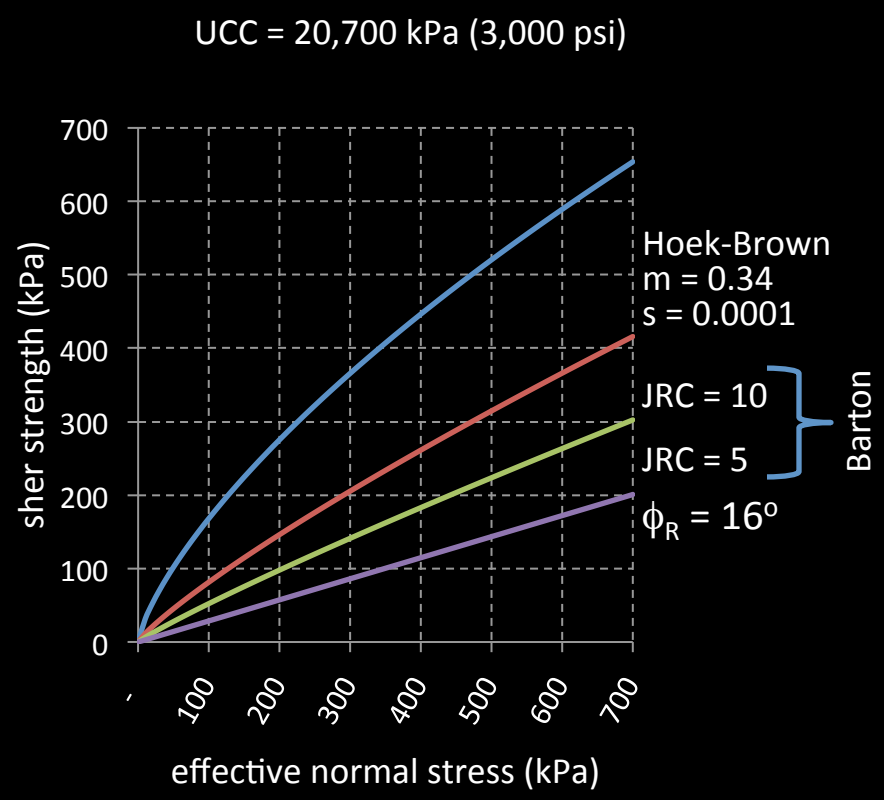
Cucaracha, Culebra, La Boca and Gatuncillo Formations



Strength Envelopes for medium and stronger tuffs



Las Cascadas Formation



Pedro Miguel & Bas Obispo Formations

1850
1900
1950
2000
1986
East Cucaracha Slide
October 13, 1986

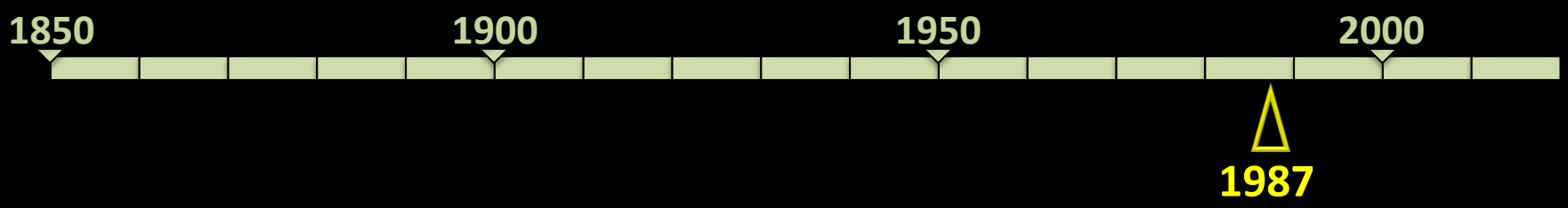
Critical Rainfall Patterns

Espinosa (1987)

On 13 October 1986:

- The 7-day accumulated antecedent rainfall
- The 14-day accumulated antecendent rainfall
- The 30-day accumulated antecedent rainfall

were the largest values in the Canal's history.



ACP's Geotechnical Advisory Board

SOWERS

DUNCAN

MORGENSTERN

SCHUSTER

MARCUSON

WESSON

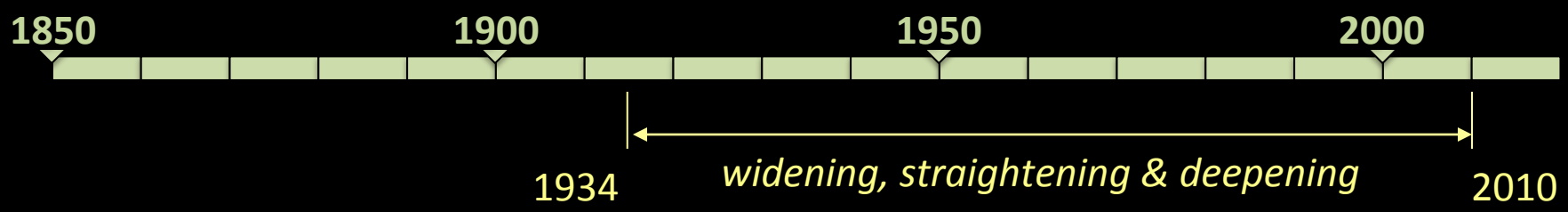
Technology transfer + credibility

Canal Personnel

1850 1900 1950 2000

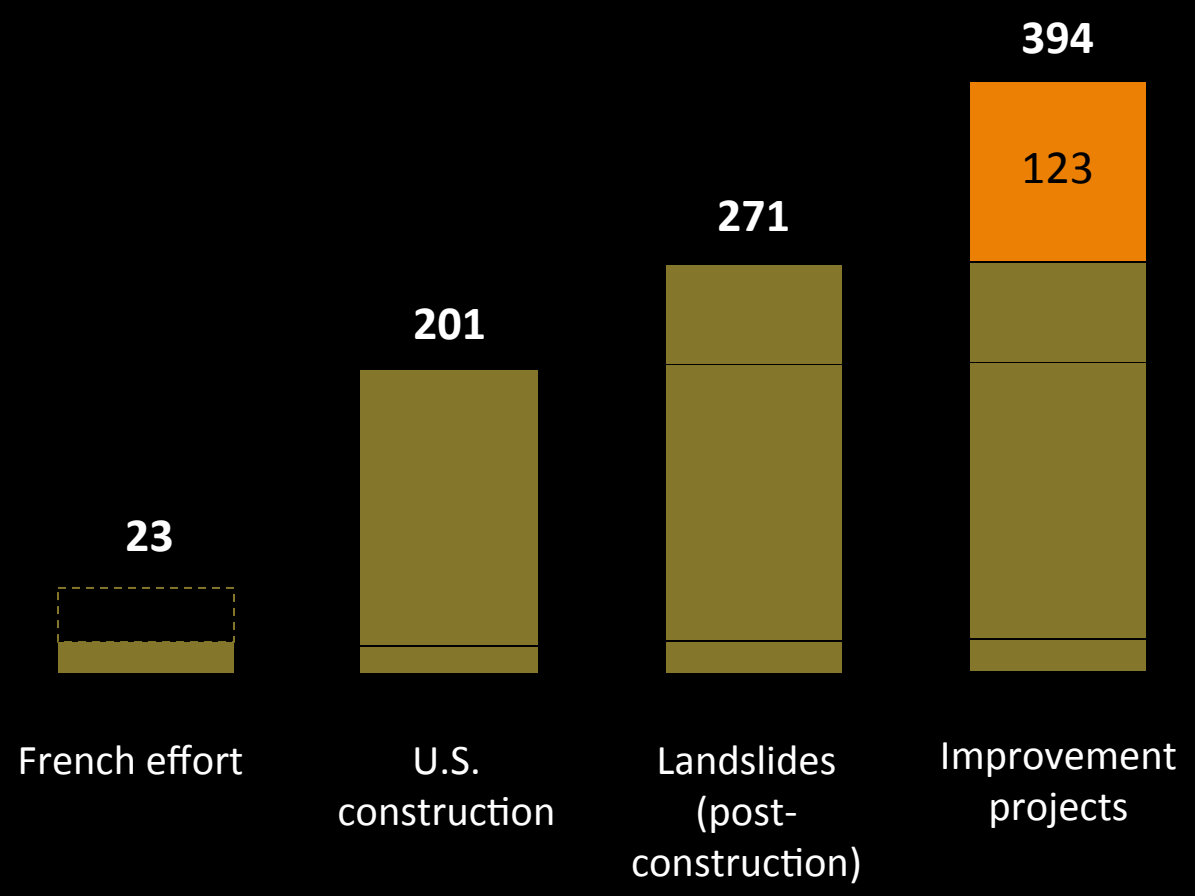
1991

ACP's Geotechnical Laboratory



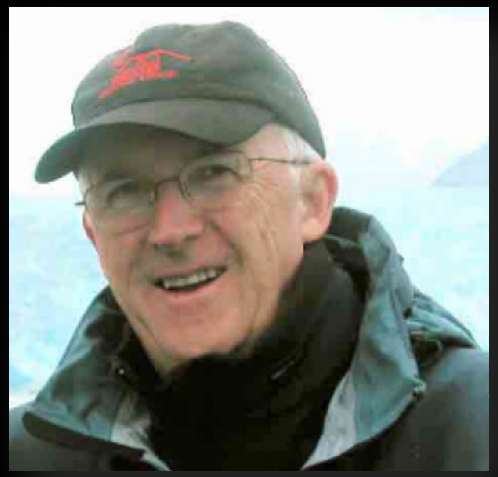
Channel improvement projects

Excavation Volumes (Mm^3)

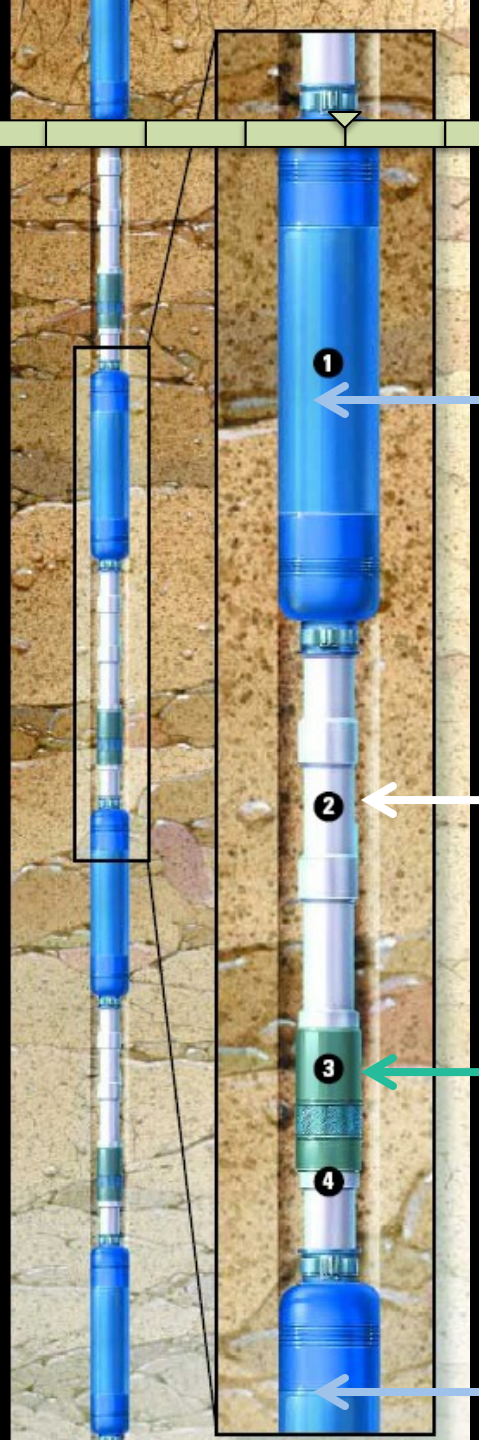


1850 1900 2000

1994



Dr. Frank Patton
Westbay Instruments



Packer

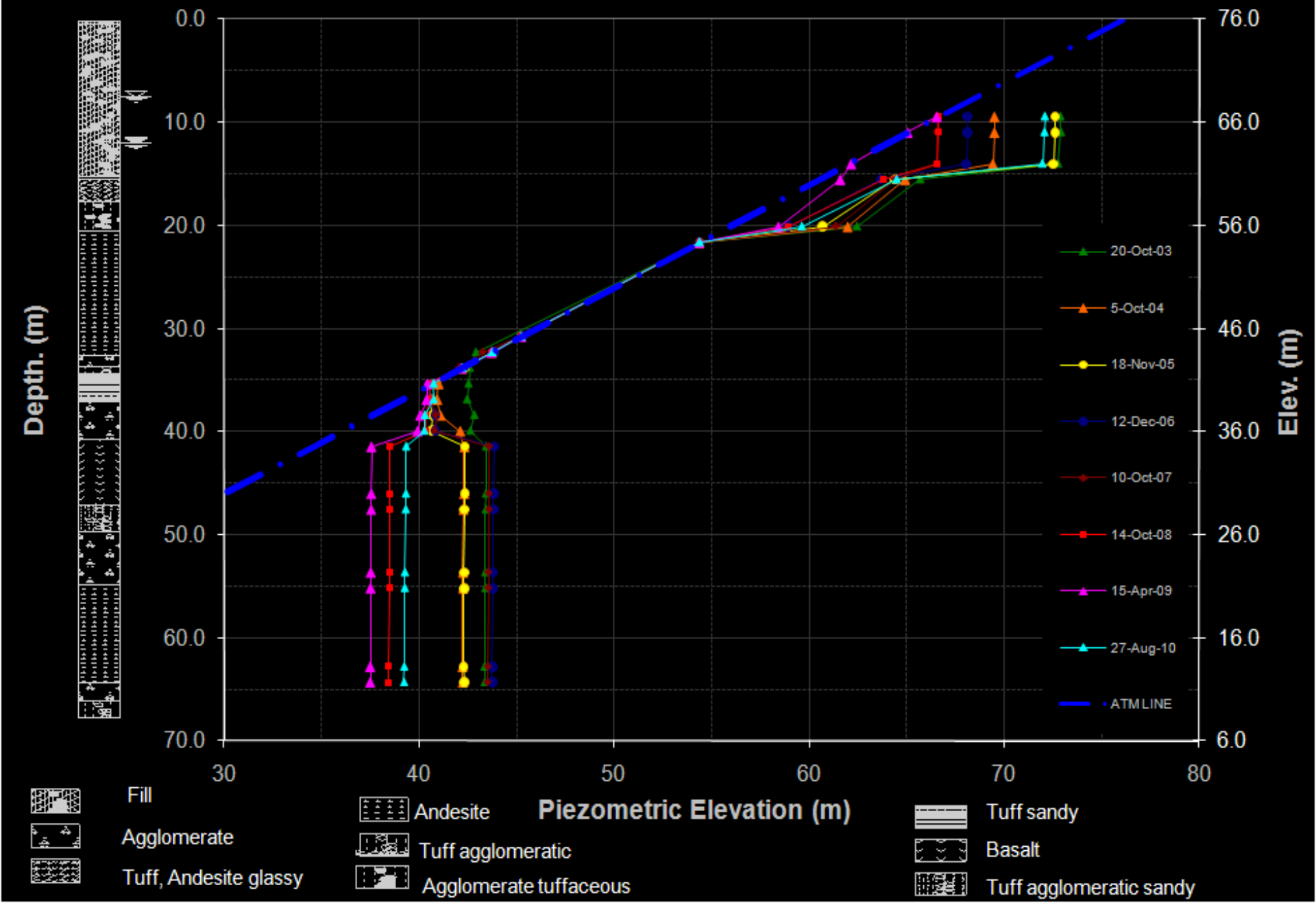
Measurement Port

Pumping Port (Hydraulic Conductivity)

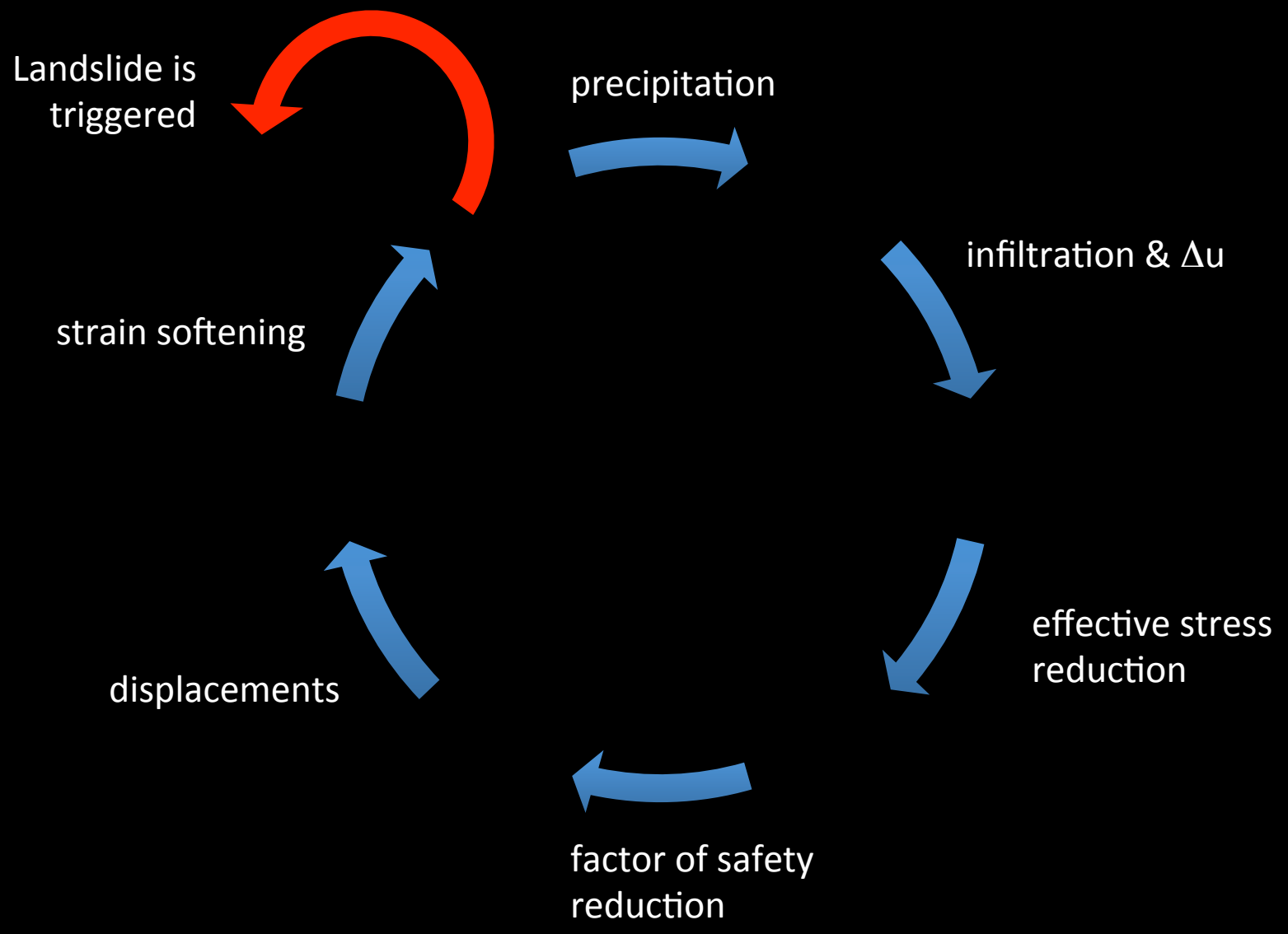
Packer

Multi-point Piezometers

Borehole SARMP-1_SARDINILLA SECTOR



Effect of Precipitation



Seismicity

1850 1900 1950 2000

1991 - 2011

Investigation of Seismic Risk in the Canal area

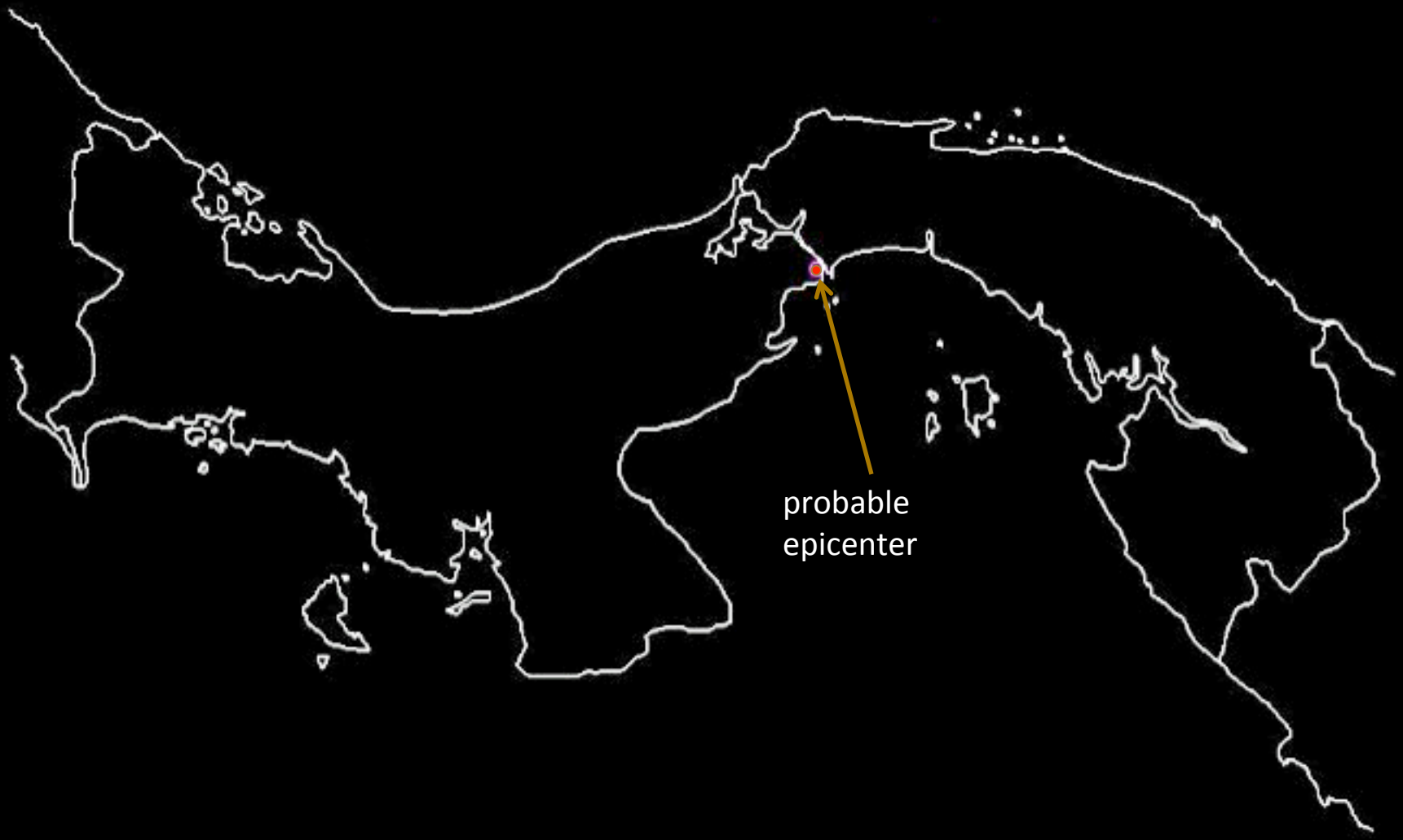
7 September, 1882 Earthquake

estimated M 7.9 Richter

Reference: "Seismicity Evaluation Report on the Tabasará Hydroelectric Project in Western Panama", Acres International Ltd., Niagara Falls Ontario, Canada (1981)

2 May, 1621 Earthquake

estimated M 5.6 – 7.0 Richter



Reference: Víquez, V. and Camacho, E. (1994), "El Terremoto de Panama La Vieja del 2 de mayo de1621: Un sismo intraplaca", Boletín de Vulcanología, OVSICORI-UNA

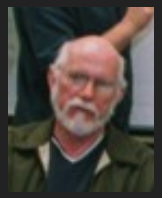
ACP's Seismic Advisory Board (2003)

WESSON

SOMMERVILLE

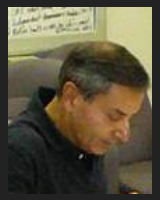
BOMMER

NADIM


CLUFF

ACP's Structural Advisory Board (2005)

HALL


CHOPRA

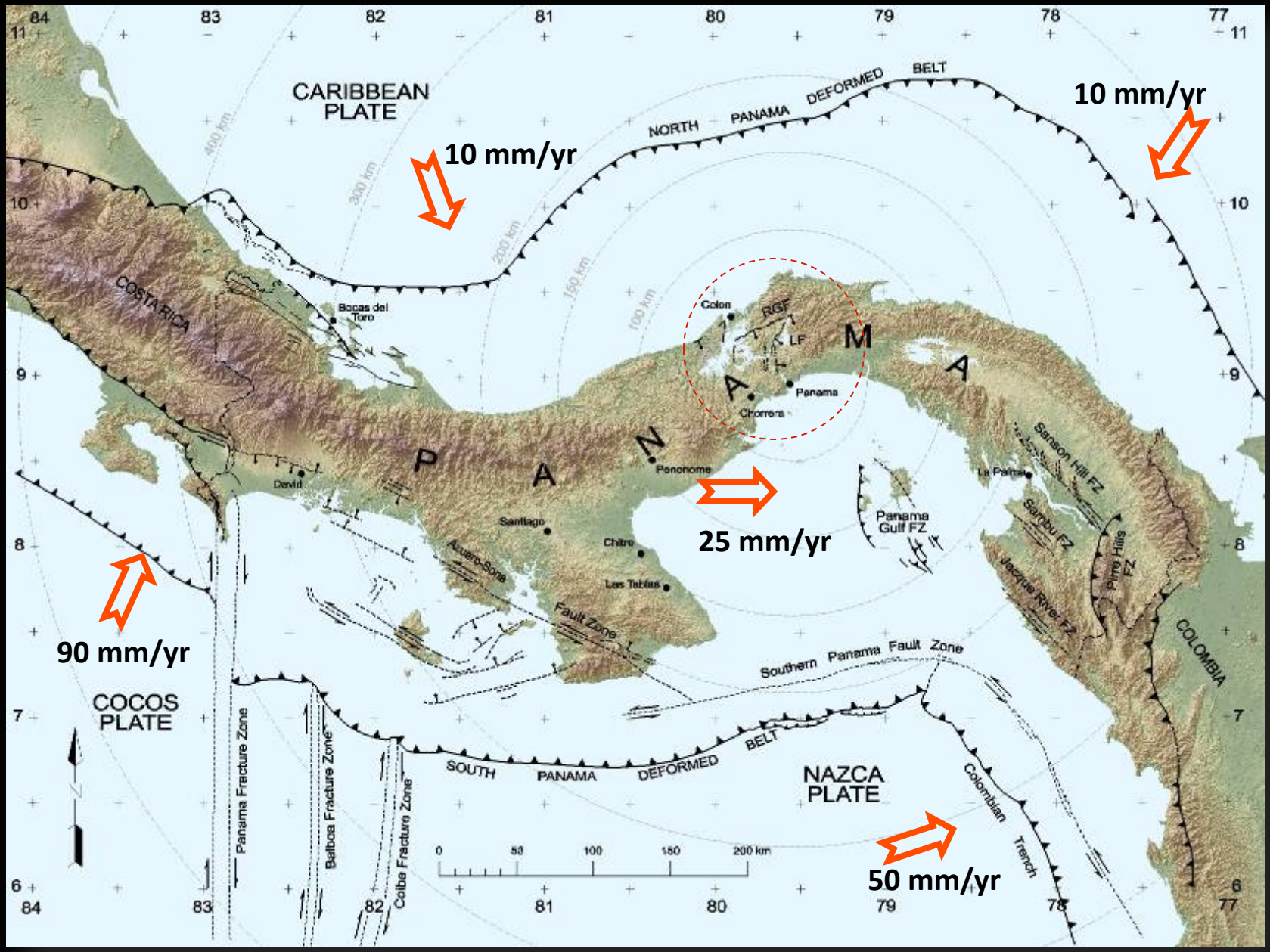
YAO

MATTEU

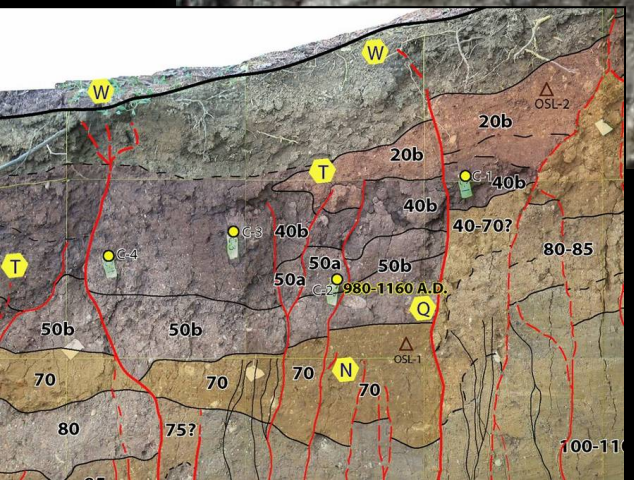
ROESSET

WEILAND

Tectonic Map of Panama (USGS)



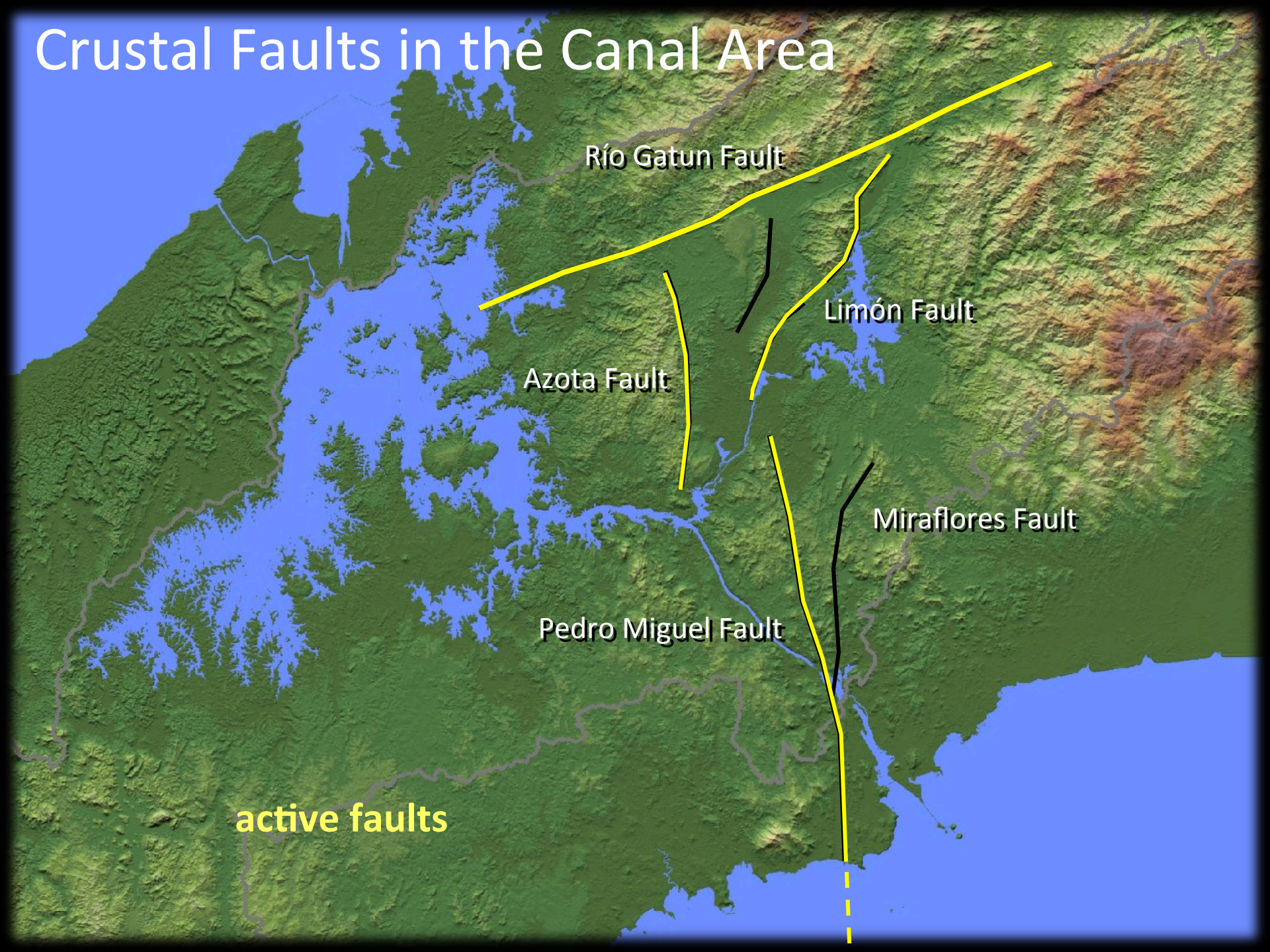
Paleoseismic Investigation



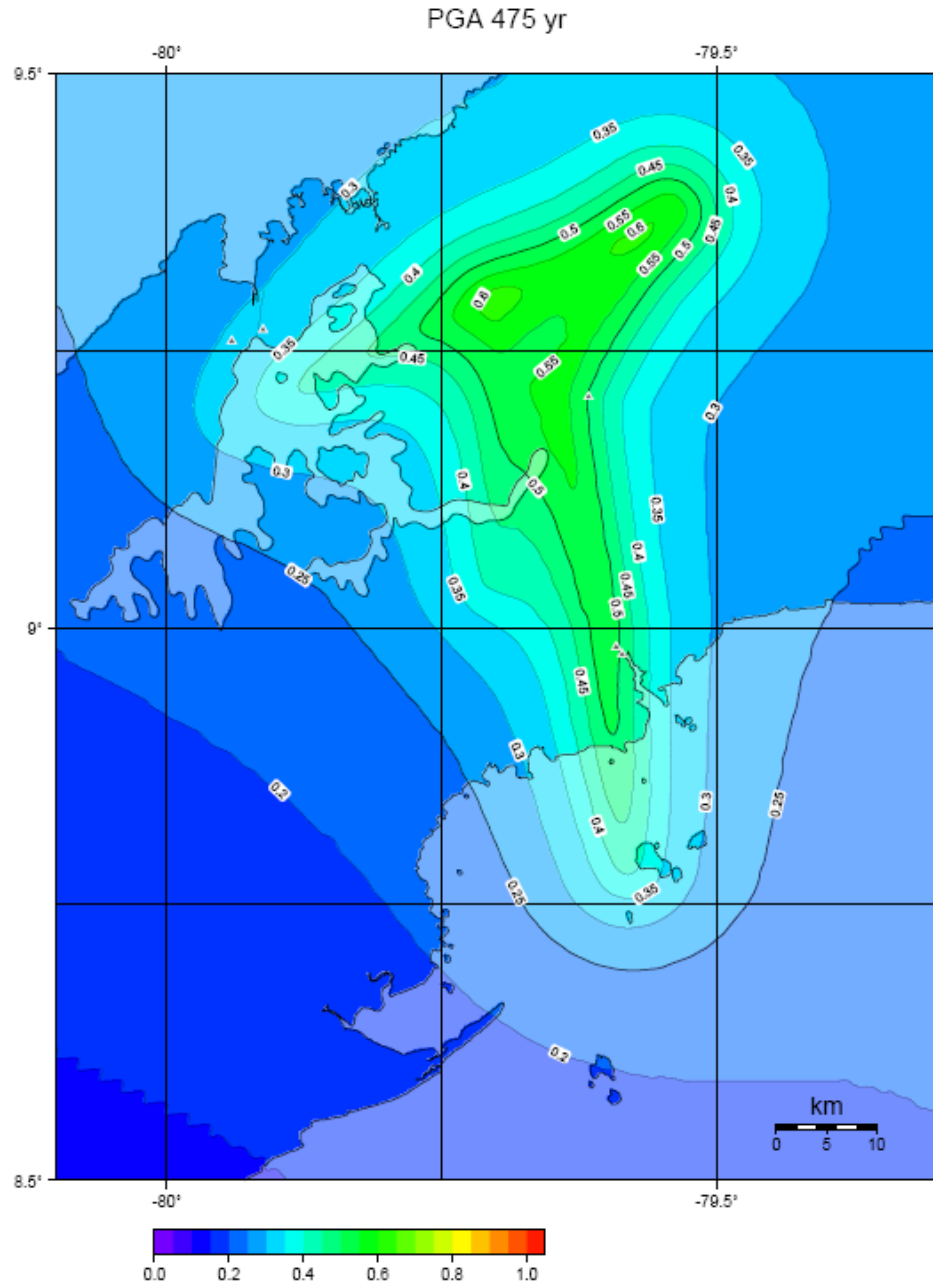
Earth Consultants International

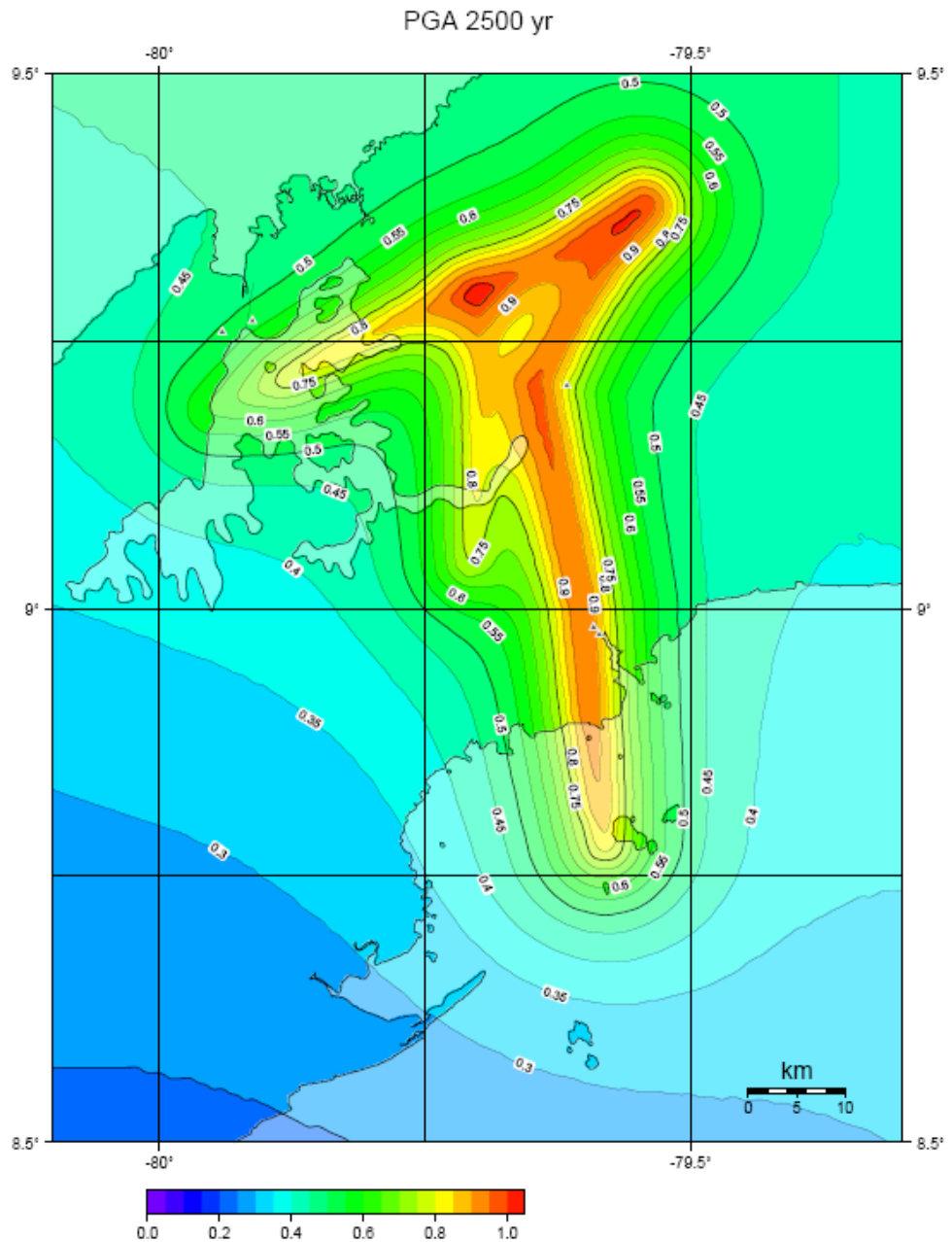
William Lettis & Associates

Crustal Faults in the Canal Area



Probabilistic Seismic Hazard Analysis (URS Corp)



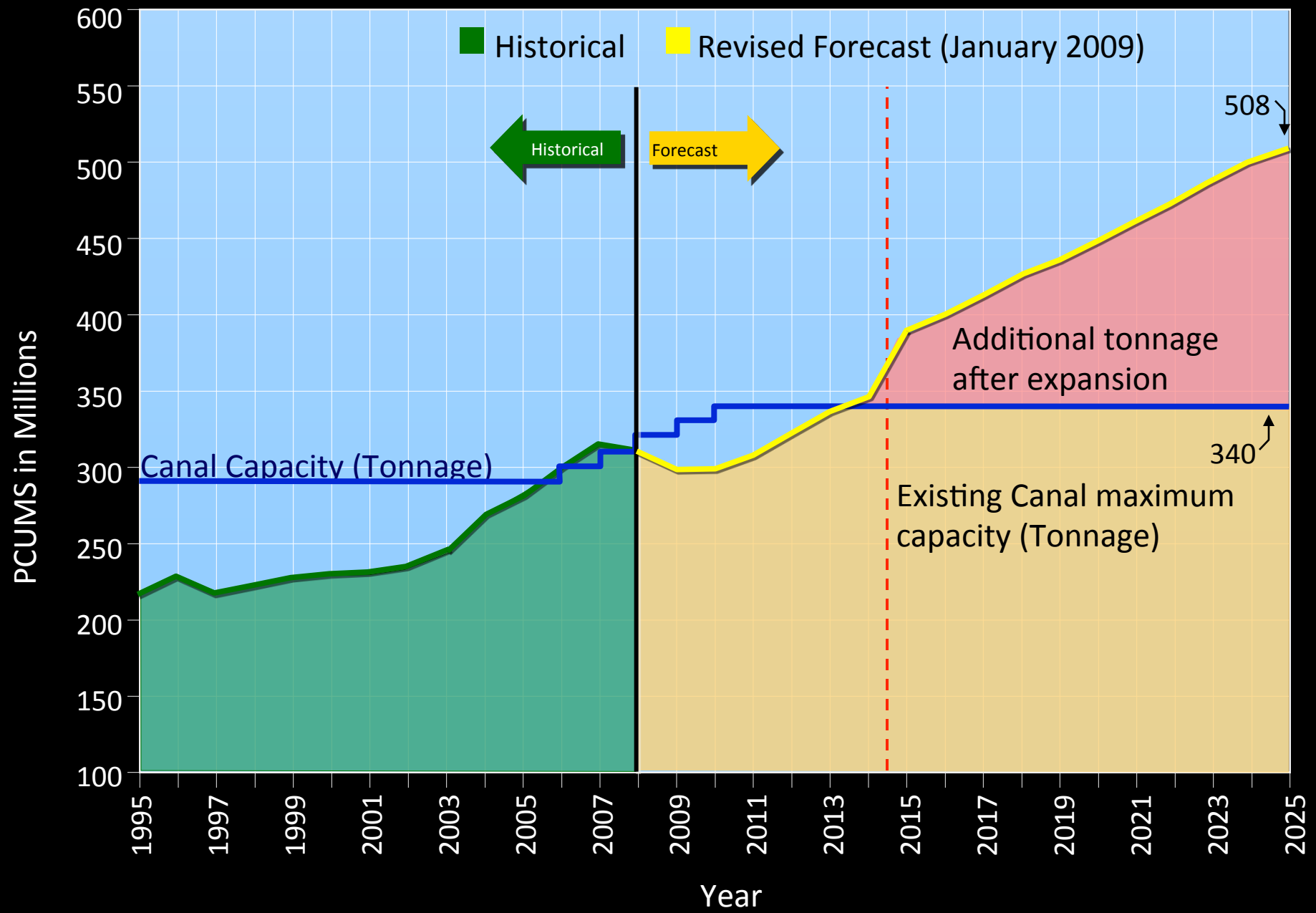


Rendering of Panama City in 1670

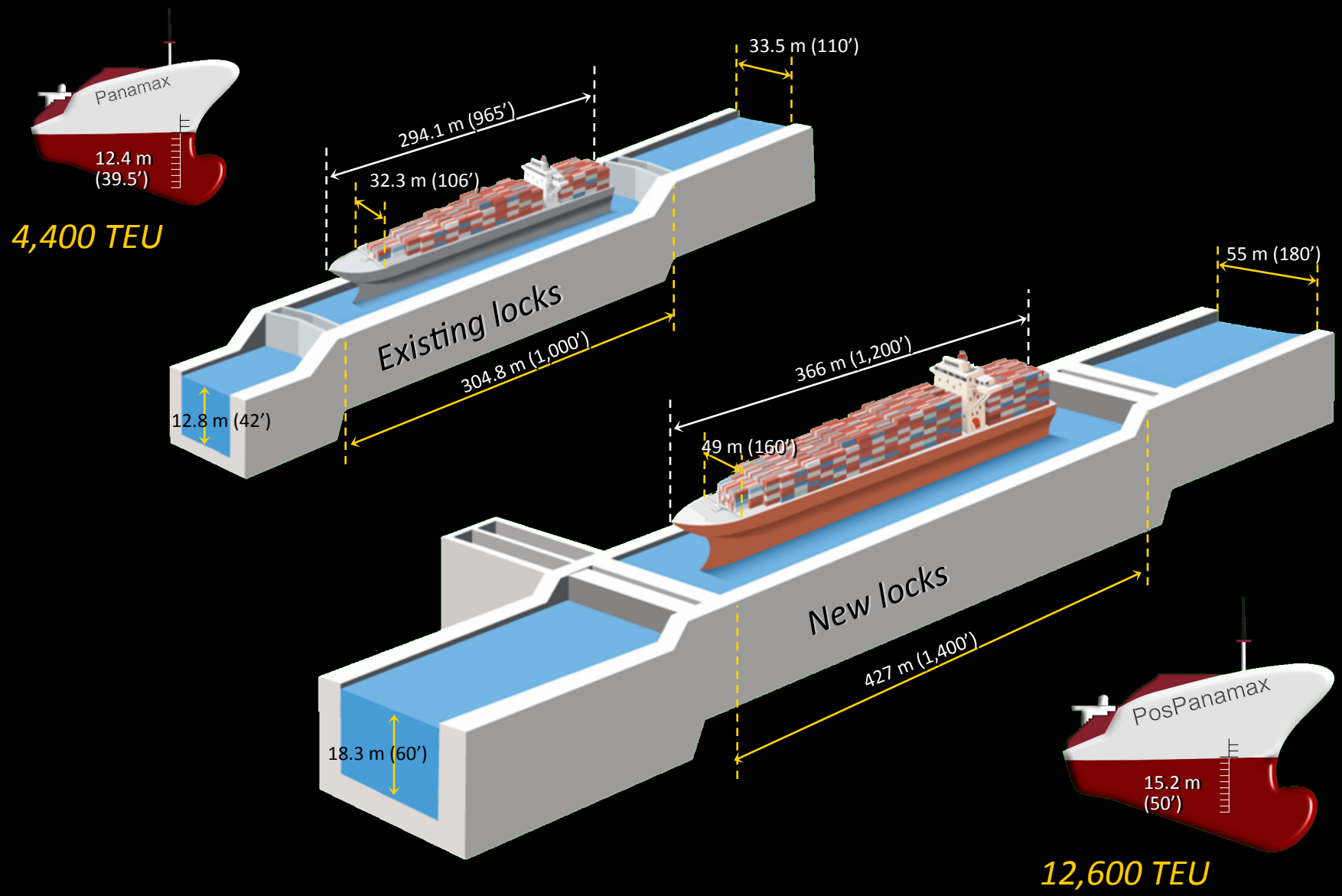
affected structures

Canal Expansion Program

Demand for shipping



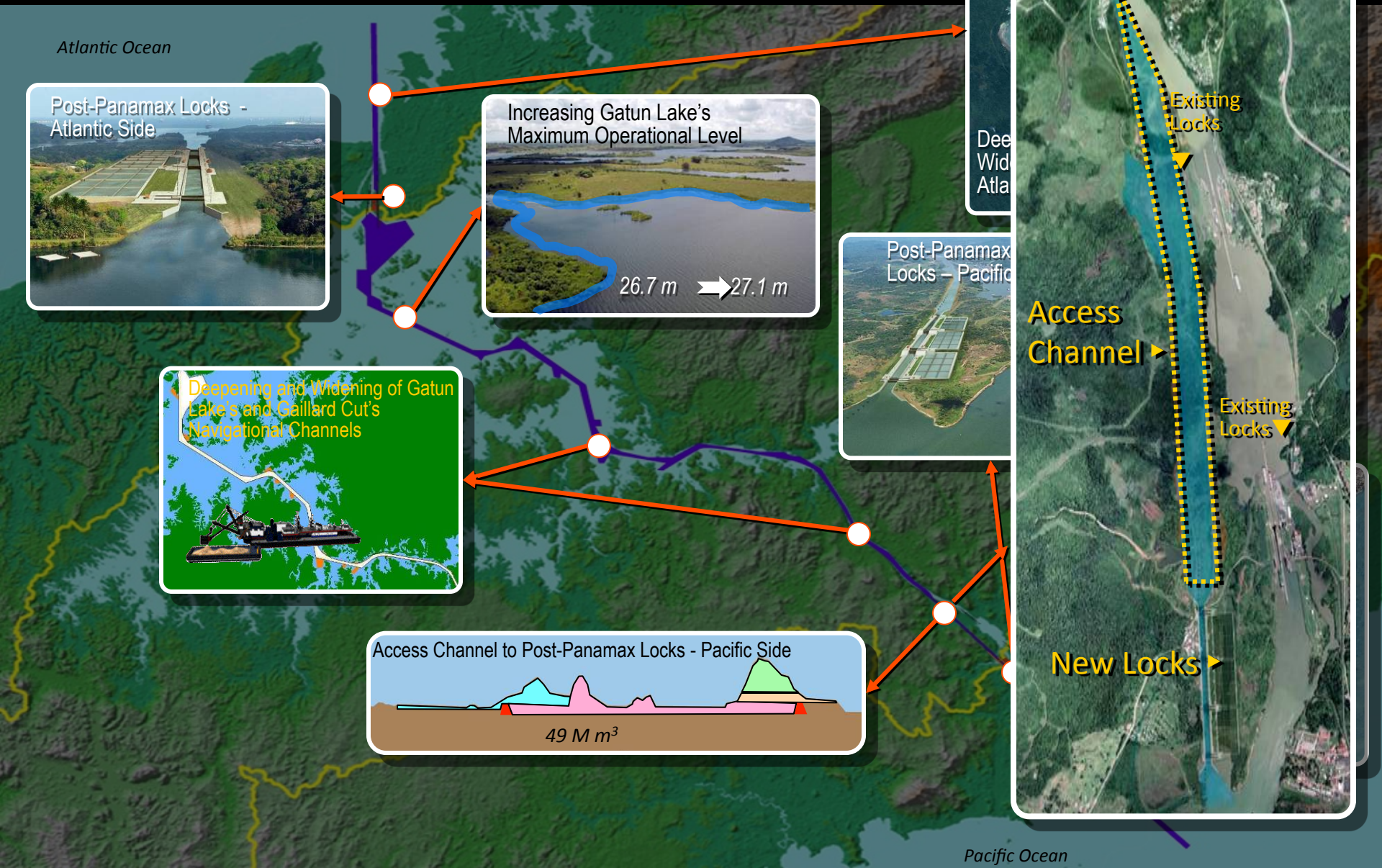
Panamax & Post-Panamax



The Canal Expansion Program

- Two new sets of Locks
- Four new Dams
- New access channels for new locks
- Widening & deepening of existing channels
- Increased freshwater regulation

Program Components



$5.25 billion investment over a 8-year period

The Post-Panamax Locks

Contractor

Construction	Sacyr Vallehermoso, S.A. (Spain) - Leader Impregilo S.p.A. (Italy) Jan de Nul n.v. (Belgium) Constructora Urbana, S.A. (Panama)
Design	Montgomery Watson Harza (US) – Leader IV Groep (Holland) Tetra Tech (US)
Gates fabricator	Cimolai (Italy)

New Pacific Locks

2.5Mm^3 of structural concrete

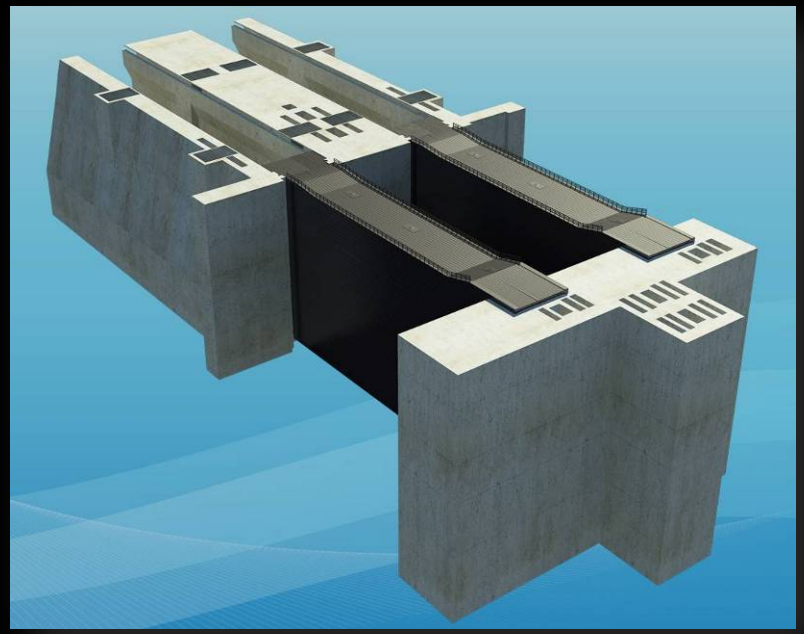
Pacific Locks construction

New Atlantic Locks

2.5Mm^3 of structural concrete

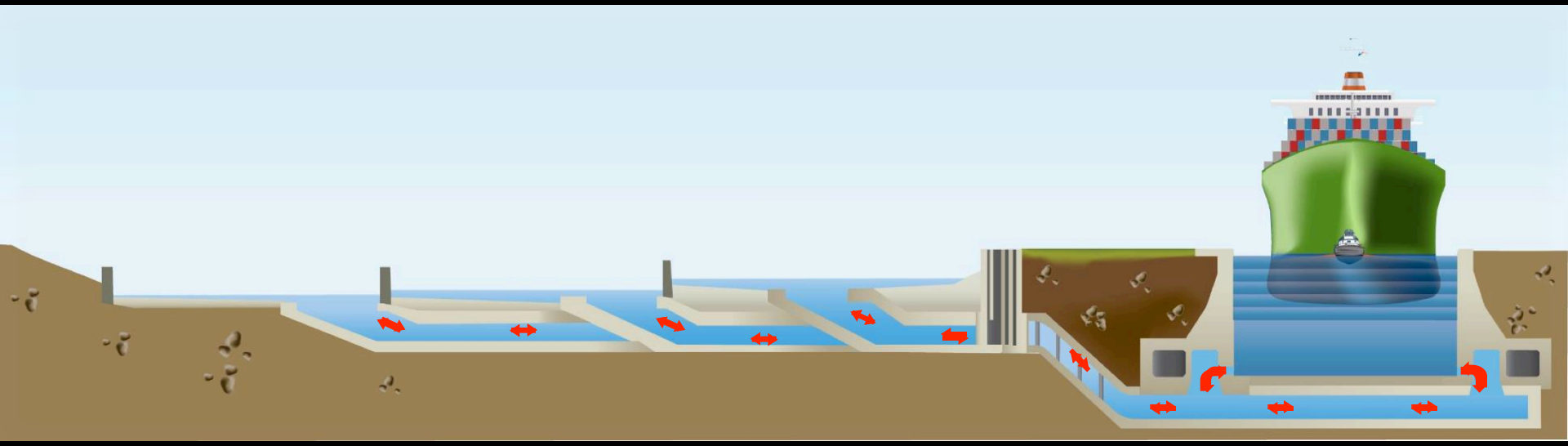
Atlantic Locks construction

Rolling gates



	Weight (tons)	Width (m)	Height (m)
AT1 – Atlantic 1	~ 2,000	8	23
AT2 – Atlantic 2	~ 3,000	10	31
AT3 – Atlantic 3	~ 3,000	10	31
AT4 – Atlantic 4	~ 3,000	10	30
PA1 – Pacific 1	~ 2,000	8	22
PA2 – Pacific 2	~ 3,000	10	33
PA3 – Pacific 3	~ 3,000	10	33
PA4 – Pacific 4	~ 3,200	10	34

Operation of the Water Saving Basins



With the WSB, the new locks will use 7% less water than the existing locks

Seismic Design Criteria

Level of structural performance

Level of ground motion	Completely operational (elastic range)	Maintain stability	Preserve reservoirs
1 /475	**Design**		
1 /1,000		**Verify stability**	
1 /2,500			**Verify reservoir retention**

PGA	
Pacific	Atlantic
0.52 g	0.33 g
0.72 g	0.42 g
0.97 g	0.55 g

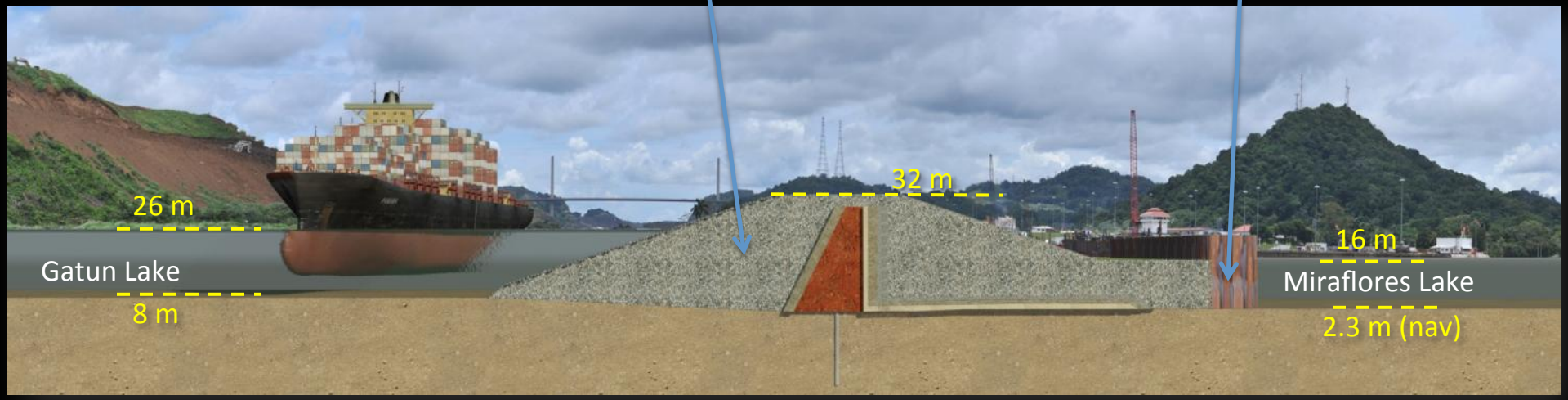
Borinquen Dams

Pedro Miguel Fault
1E
1W
2W
2E

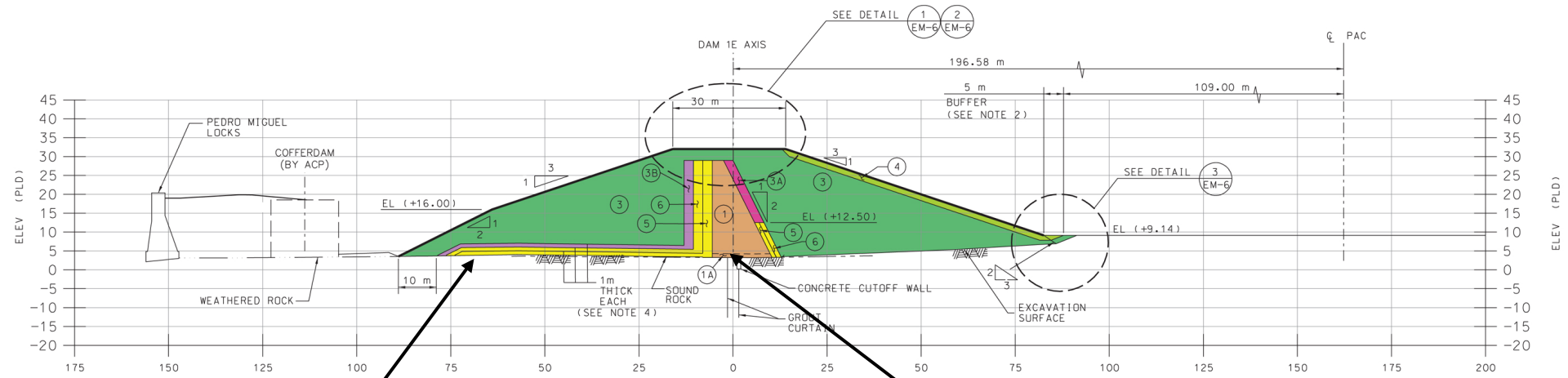
Borinquen Dam 1E

Borinquen Dam 1E

Cross section



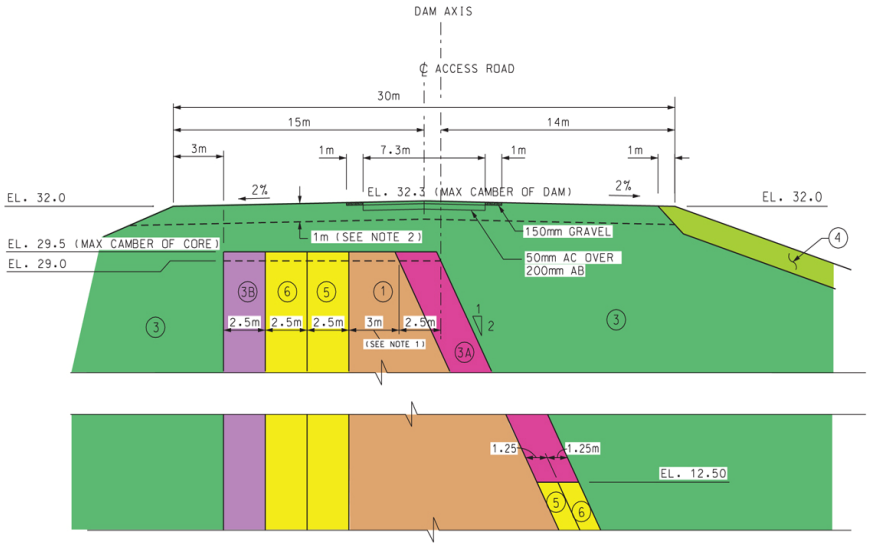
Borinquen Dam 1E design (URS Corp)



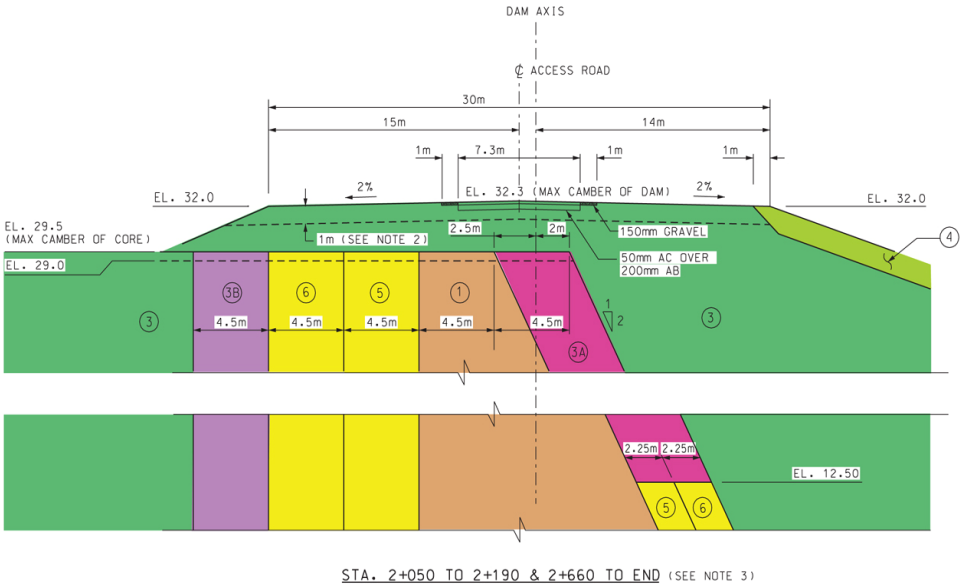
Weathered rock

MAXIMUM SECTION AT STA. 1+000 (WITHOUT CAMBER)

Sound rock



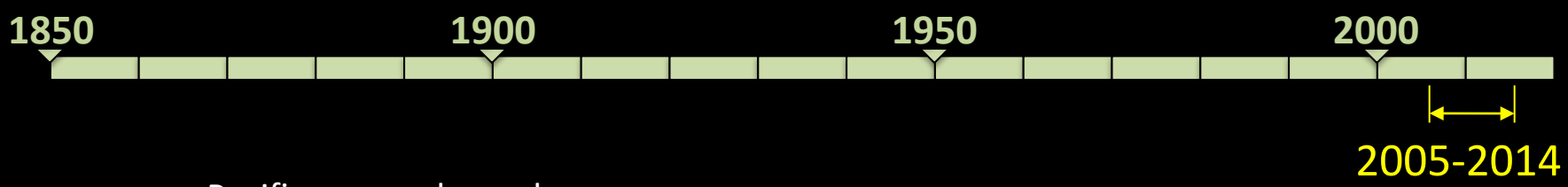
Regular section



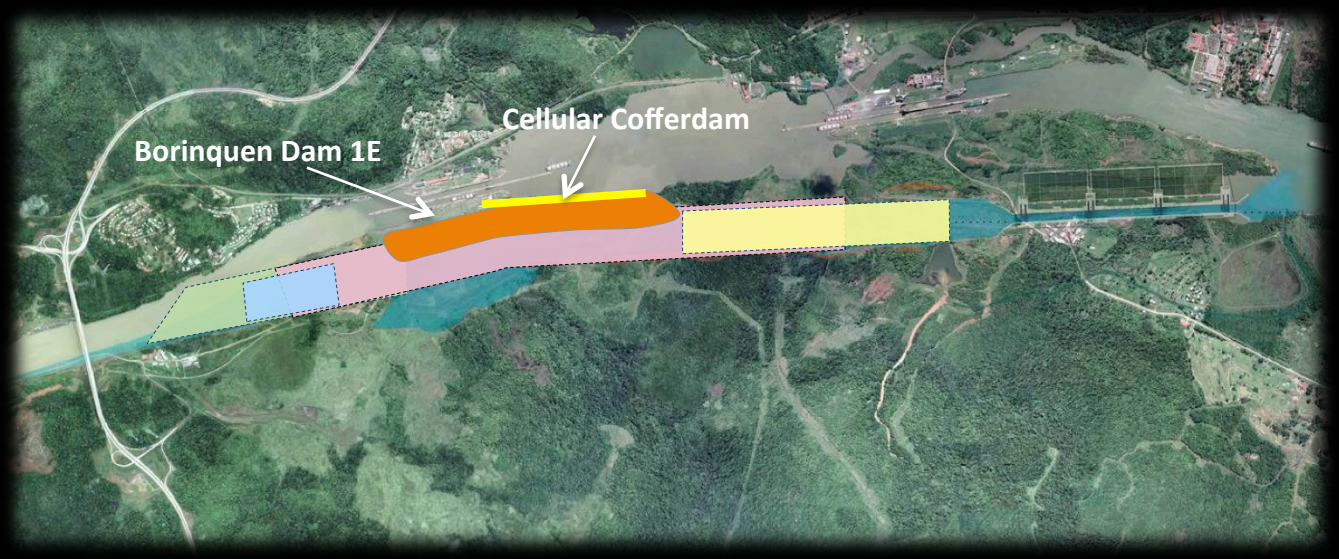
Section over fault crossing

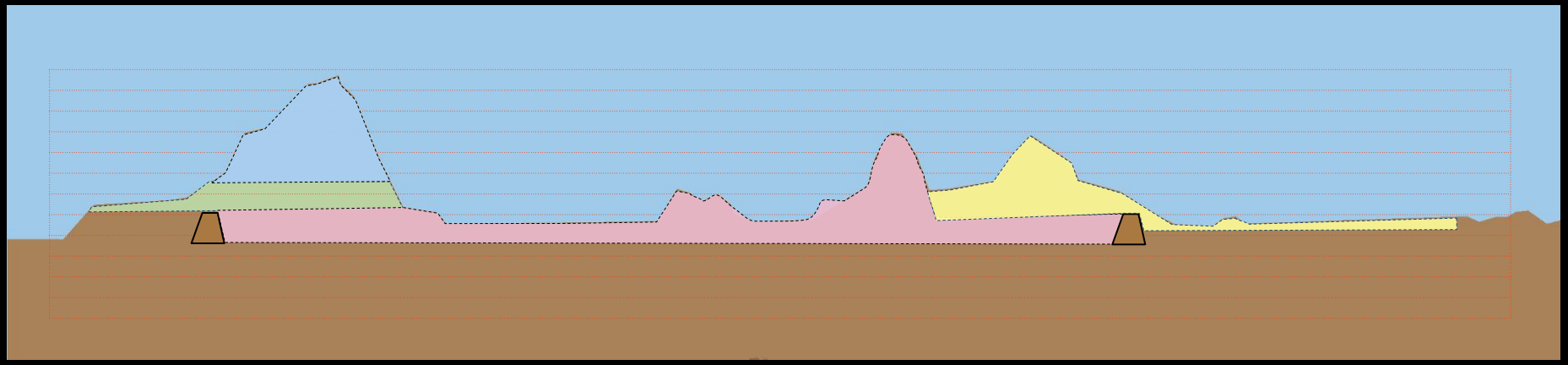
Pacific Access Channel

(the second Gaillard Cut)



Pacific access channel

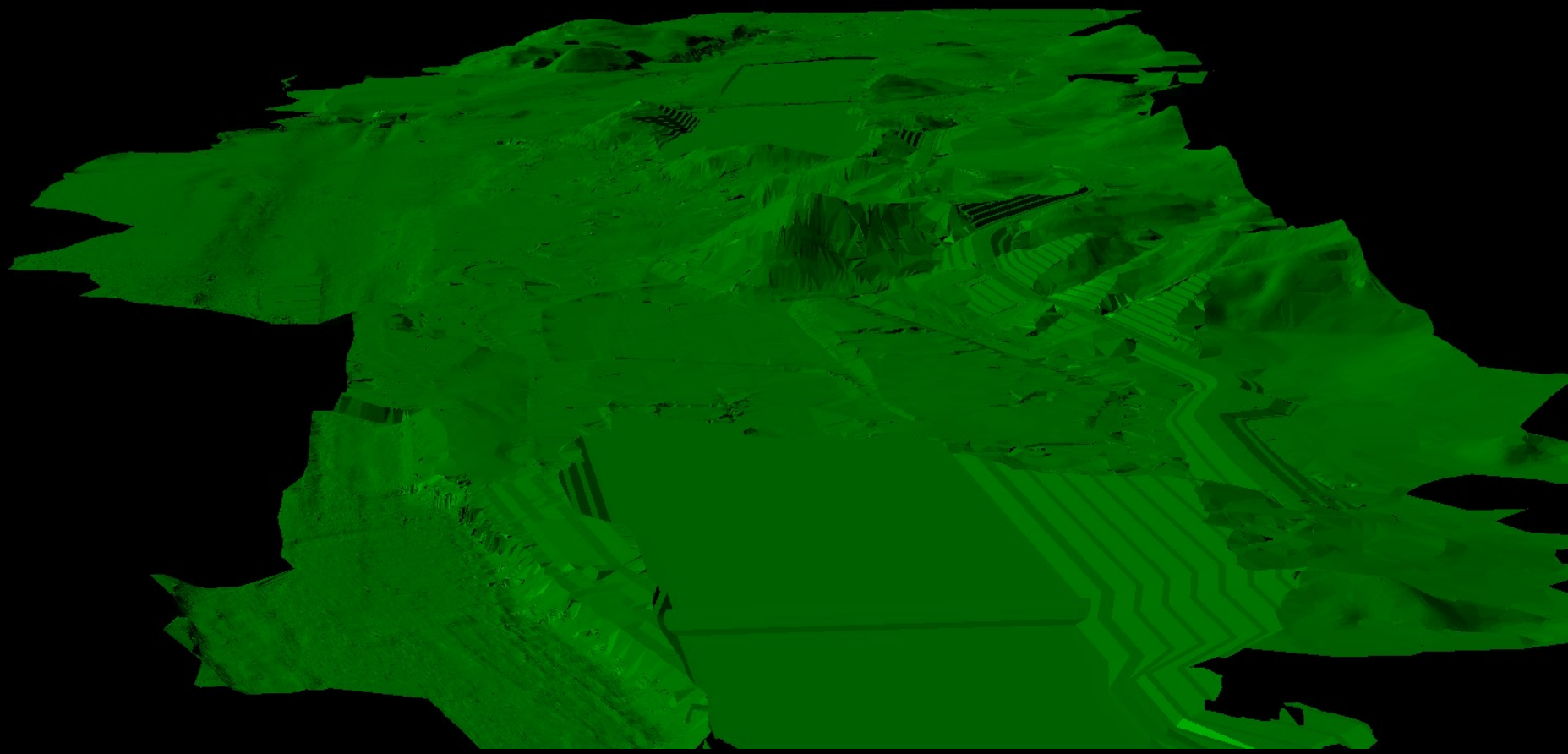




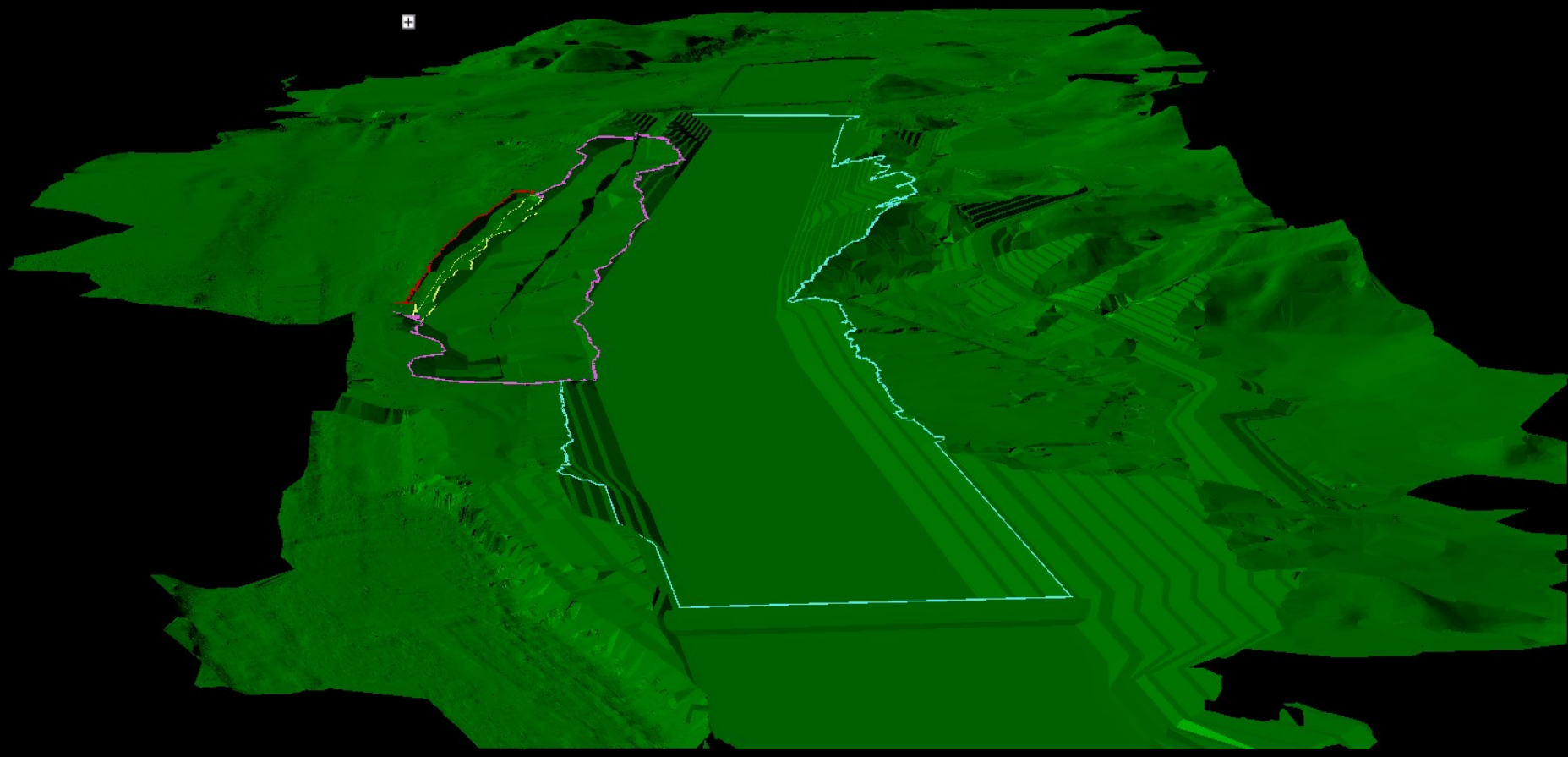
PAC-4 sequence of construction

Rendering of photo of Sept 17, 2008 (looking south)

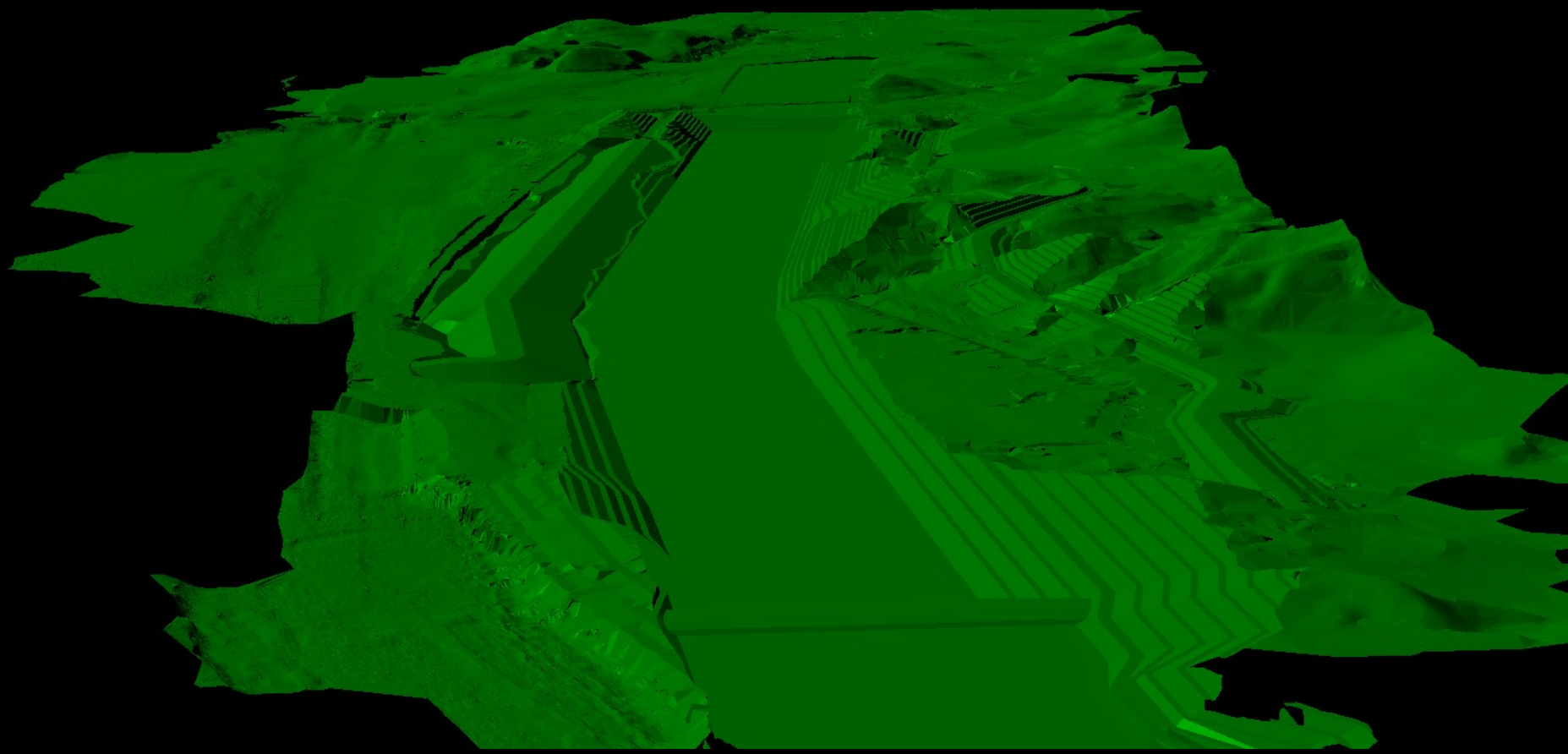
Initial condition



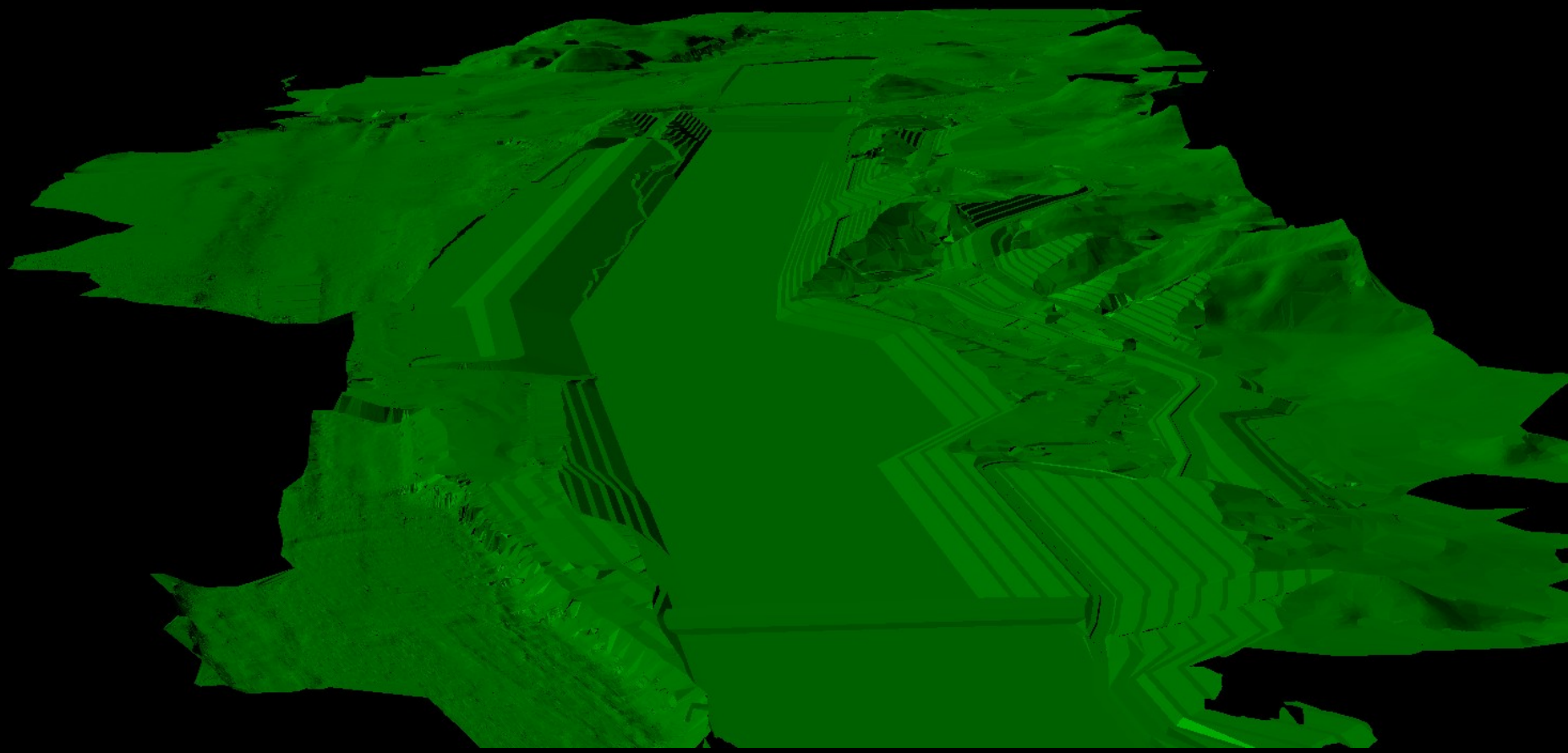
Excavation



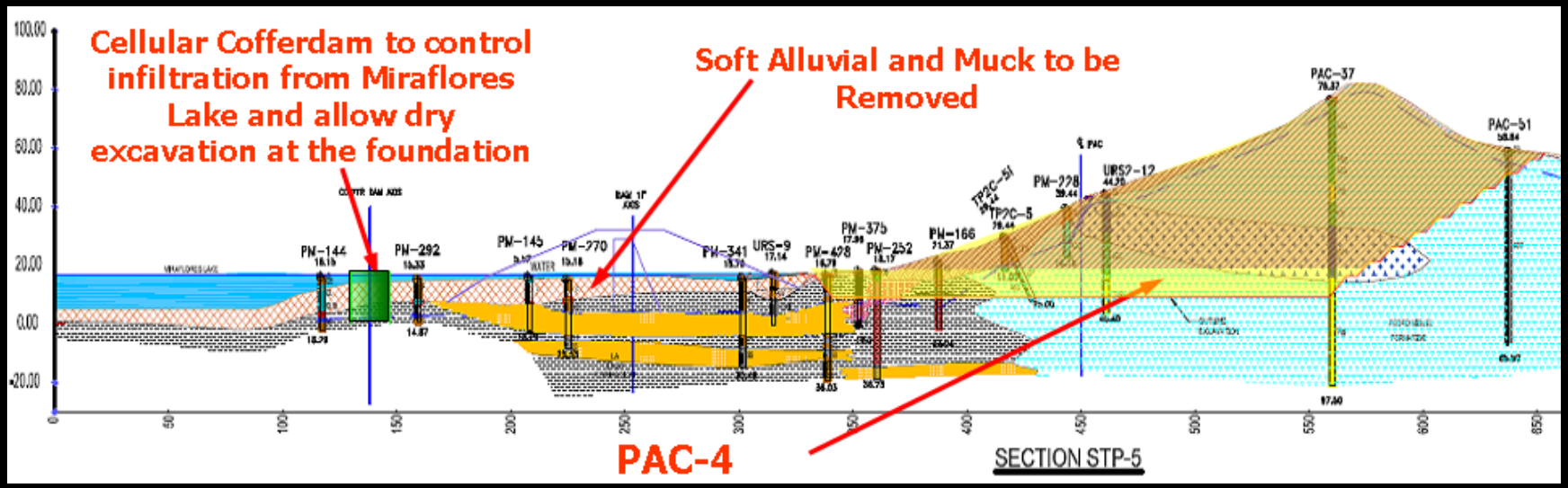
Dam construction



Final configuration



Design criteria



- Prepare Geologic model of the slope
- Search for critical failure mechanism
- Determine FS in existing condition
- Maintain FS in excavated condition

Construction of Cofferdam (PAC-4)

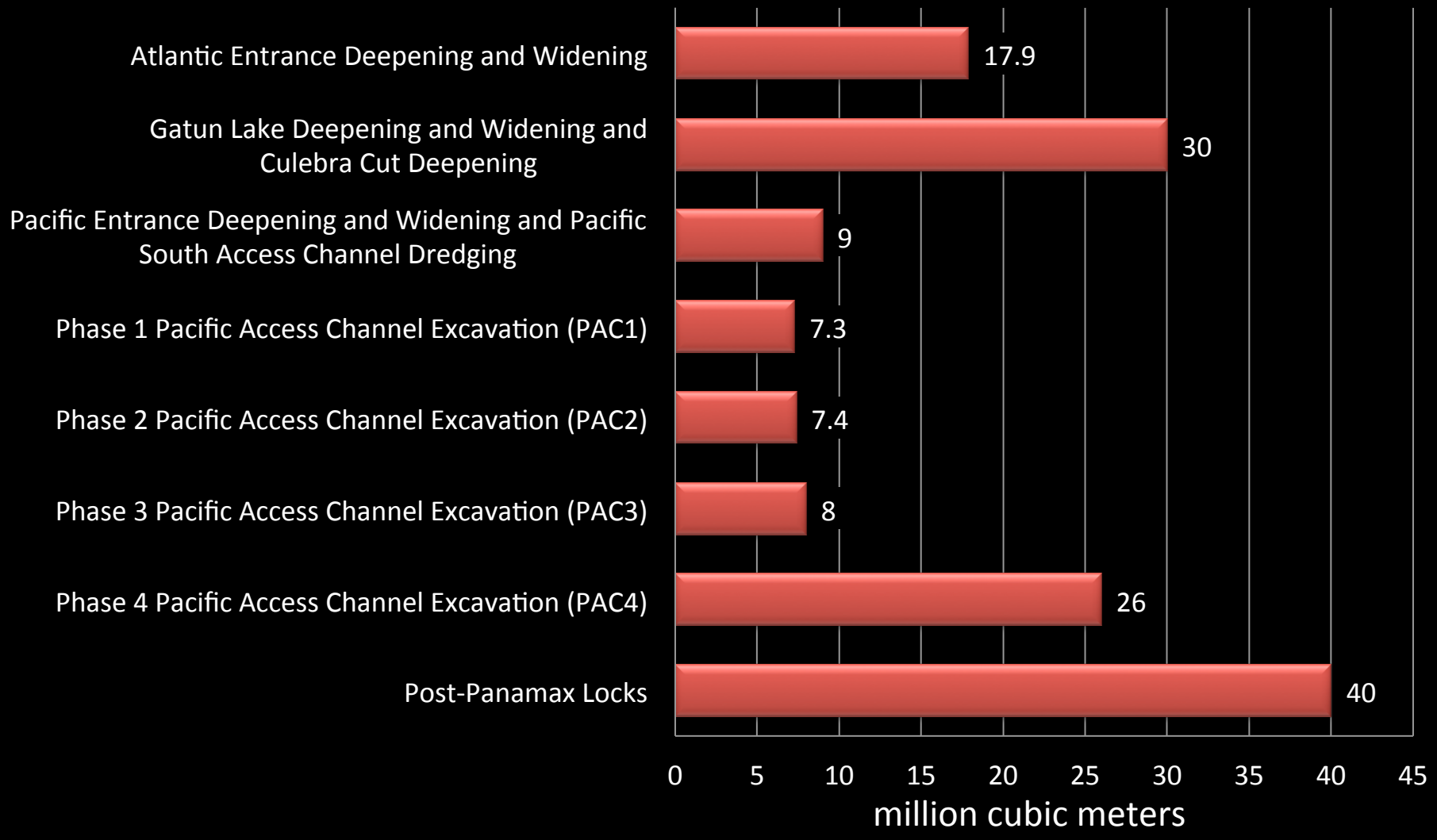
Excavations (PAC-4)

NYK LINE

Excavation

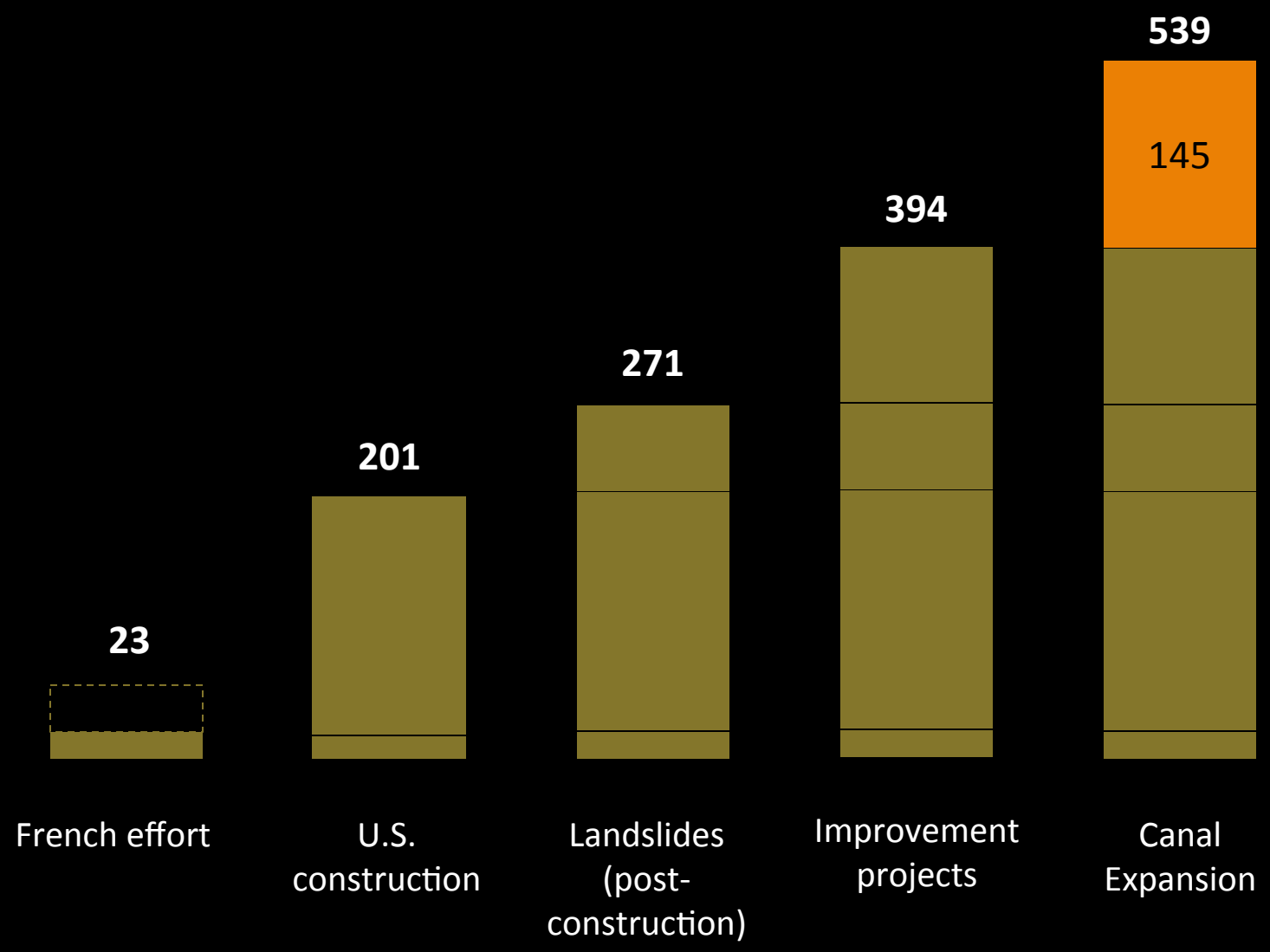
Atlantic Locks

Excavations for the Canal Expansion Program



Total excavation = 145 Mm3 (46% completed)

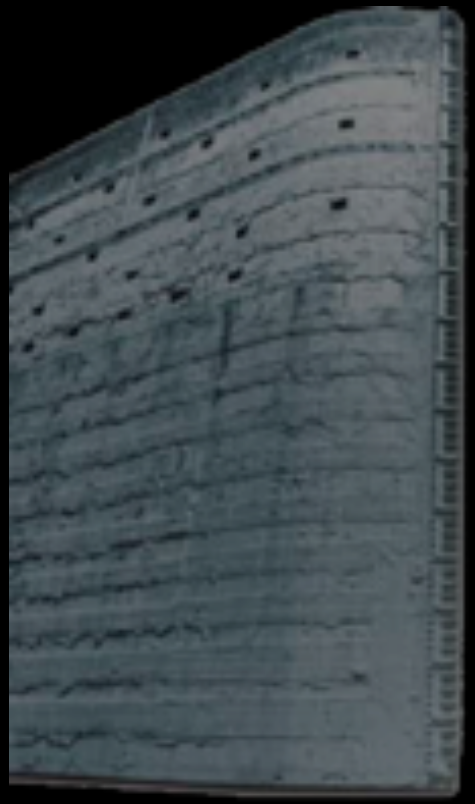
Excavation Volumes (Mm^3)



Overall progress of Canal Expansion Program = 21%

Final thoughts

- Canal builders
- Geotecnical Engineering
- Expected lifetime of Canal?



CANAL DE PANAMÁ

April 8, 2011

Reference Material

Some Canal construction statistics

- Workers: 56,307
- Cost to 1914: $639M
- Total excavation: 178 M m^3
- Volume of Gatun Dam: 16.8 M m^3
- Elevation of Gatun lake: 85’ PLD
- Area of Gatun lake: 436 km^2
- Area of watershed: 2,313 km^2
- Useful storage of Gatun lake: 766 M m^3
- Water required for one transit: 52 M gallons
- Filling/Emptying of lock chambers: 10 min
- Power required to open miter gates: 40 HP
- Electrical systems to power towing locomotives developed by young upstart: General Electric