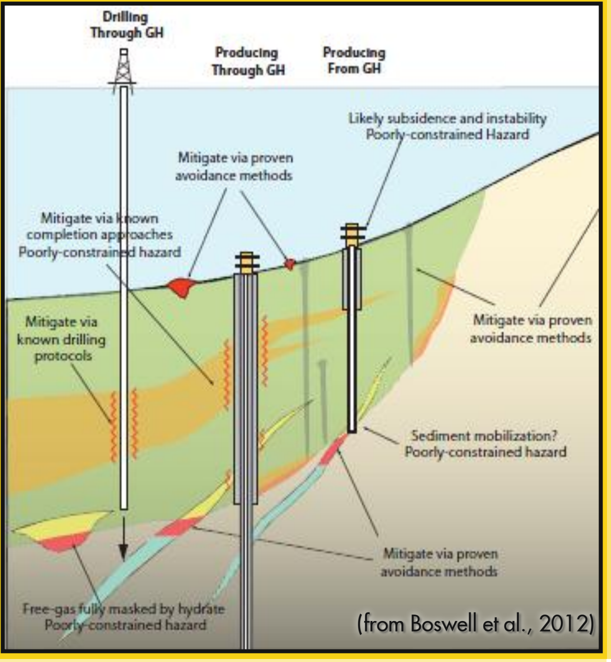
Gas Hydrates as a Geohazard:
What Really Are the Issues?

R. Craig Shipp, Ph.D.

Shell International Exploration and Production Inc.
Houston, Texas

Methane Hydrate Advisory Committee
Galveston, Texas

27 March 2014



(from Boswell et al., 2012)

Definitions and Cautionary Note

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate entities. In this presentation "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this presentation refer to companies over which Royal Dutch Shell plc either directly or indirectly has control. Companies over which Shell has joint control are generally referred to "joint ventures" and companies over which Shell has significant influence but neither control nor joint control are referred to as "associates". In this presentation, joint ventures and associates may also be referred to as "equity-accounted investments". The term "Shell interest" is used for convenience to indicate the direct and/or indirect (for example, through our 23% shareholding in Woodside Petroleum Ltd.) ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

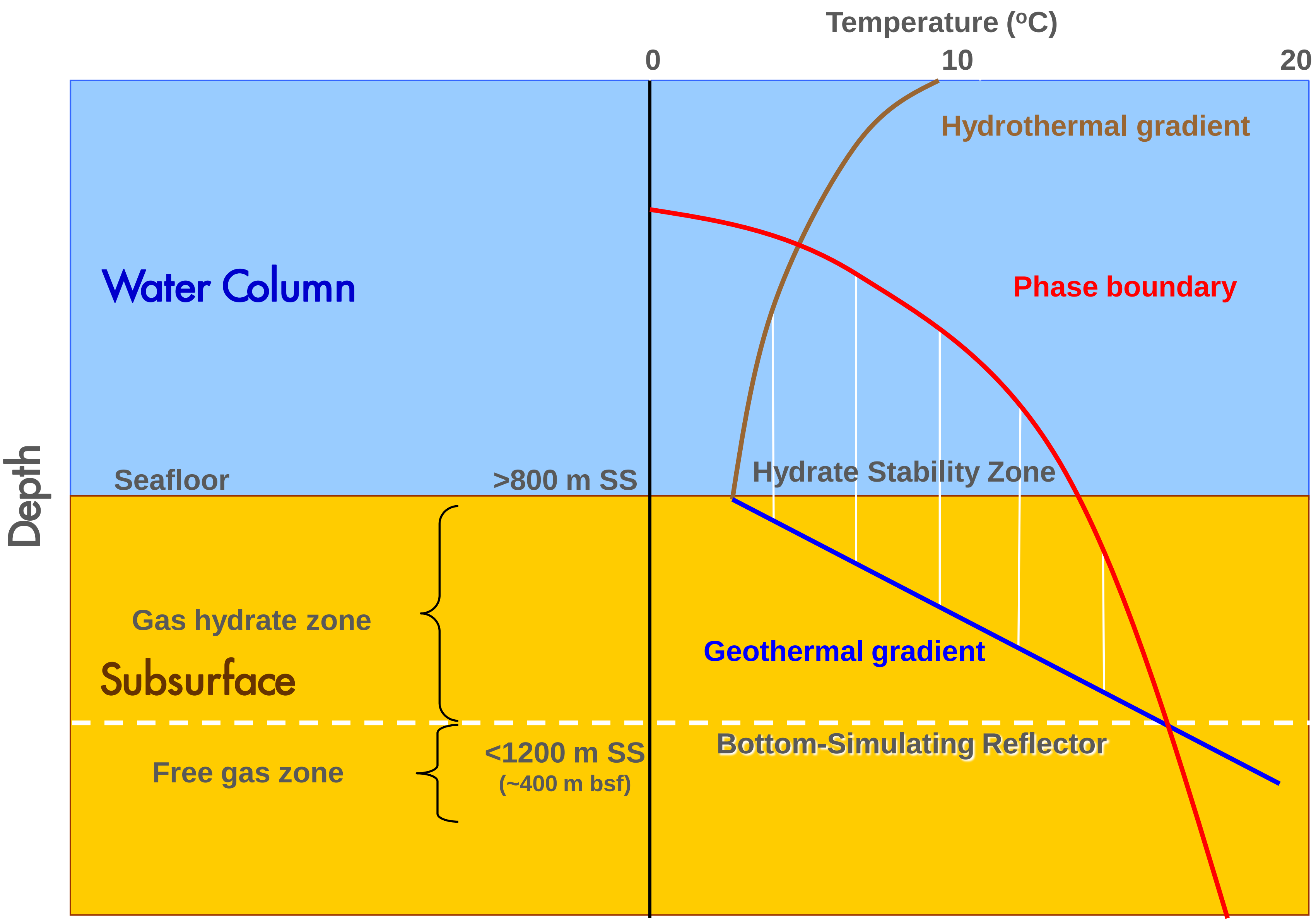
This presentation contains forward-looking statements concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this presentation, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. All forward-looking statements contained in this presentation are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's 20-F for the year ended December 31, 2012 (available at www.shell.com/investor and www.sec.gov). These risk factors also expressly qualify all forward looking statements contained in this presentation and should be considered by the reader. Each forward-looking statement speaks only as of the date of this presentation, 26 March 2014. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this presentation.

We may have used certain terms, such as resources, in this presentation that United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. U.S. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov. You can also obtain these forms from the SEC by calling 1-800-SEC-0330.

Acknowledgments

- Ray Boswell, NETL
- Tim Collett, USGS
- Brandon Dugan, Rice Univ.
- Jarle Husebø, Statoil
- Dan McConnell, Fugro
- Charlie Paull, MBARI

Marine Gas-hydrate Stability



Introductory Thoughts

- Understanding of the potential geohazards issues for gas hydrate were slow to evolve, because most experience was limited, anecdotal, and frequently proprietary information within energy companies.

- Definition of what actually is a gas hydrate geohazard is interpretative - one of scale in size and time.
  - Latent natural hazards triggered by human activities that are of short duration, occurs locally (i.e., the wellbore), and are more restricted in scope -> Operational Geohazards
  - Caused by geologic process that go on for a long time, can occur over wide area, and are bigger in scope -> Naturally Occurring Geohazards

- Marine seafloor vs. subsurface gas-hydrate geohazards issues -
  - Mostly focusing on marine subsurface geohazard issues in this presentation
  - Seafloor geohazards present an entirely different set of issues – but areally very restricted and are much easier to identify remotely

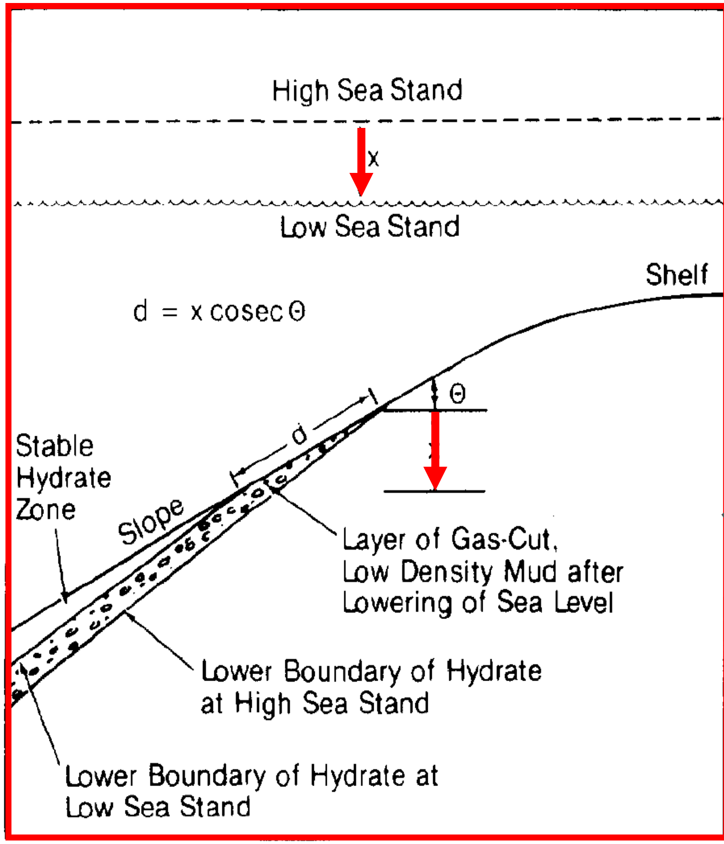
Presentation Outline

- Historical evolution of gas hydrate as a geohazard
- Potential *operational geohazards* related to gas hydrate
- Potential *naturally occurring geohazards* related to gas hydrate
- Summary thoughts and questions

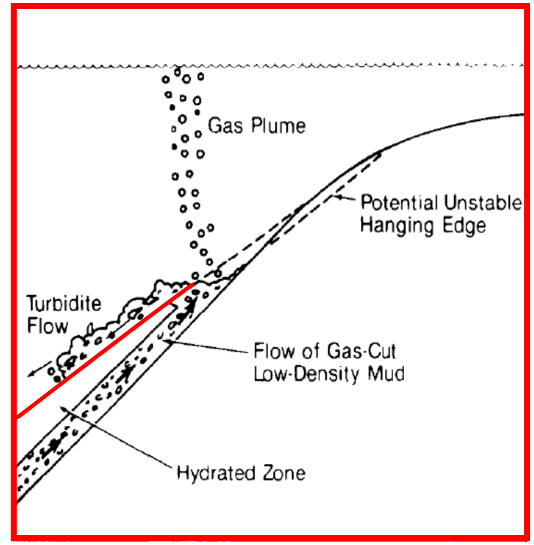
Evolution of Potential Gas-hydrate Geohazards

- **Early literature of the1970's and 1980's** – Disaster scenarios and "sky may be falling" (e.g., McIver, 1974; 1977; 1982; Taylor, 1980)
- **Mid to late 1990's** – Issues raised by ODP Leg 164 to Blake Ridge and maturing of deepwater exploration (mostly gulf of Mexico); concern for presence of free gas (e.g., Borowski and Paull, 1997; Paull, 1997; Roberts et al., 1999)
- **Mostly Early 2000's**
  - Government and energy industry perspective (e.g., Dillion and Max, 2001; Hovland et al., 2001; Hovland and Gudmestad, 2001; Hooper, unpublished)
  - Compilation of Arctic experiences (e.g., Yakushev and Collett, 1999; Collett and Dallimore, 2002)
- **Mid to late 2000's** – Echoing earlier concerns with some actual real data and more quantification (e.g., Nimblett et al., 2005; Lane, 2005; Birchwood et al., 2008; Hadley et al., 2008; Peters et al., 2008)
- **Early 2010's** – Perspective and overview with much more data (e.g., McConnell et al., 2012; Boswell et al., 2012)

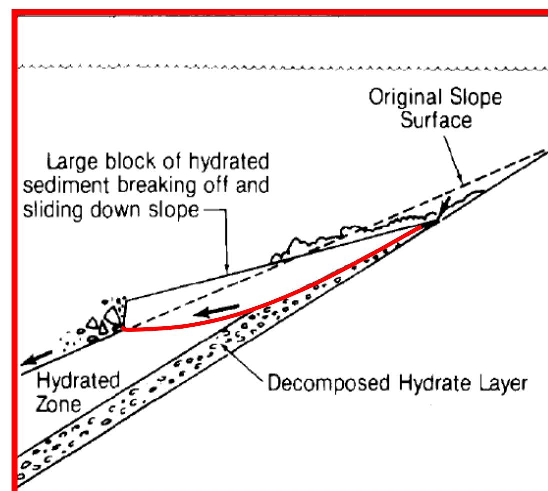
Early Concern Over Slope Instability



Cause Turbidity Currents



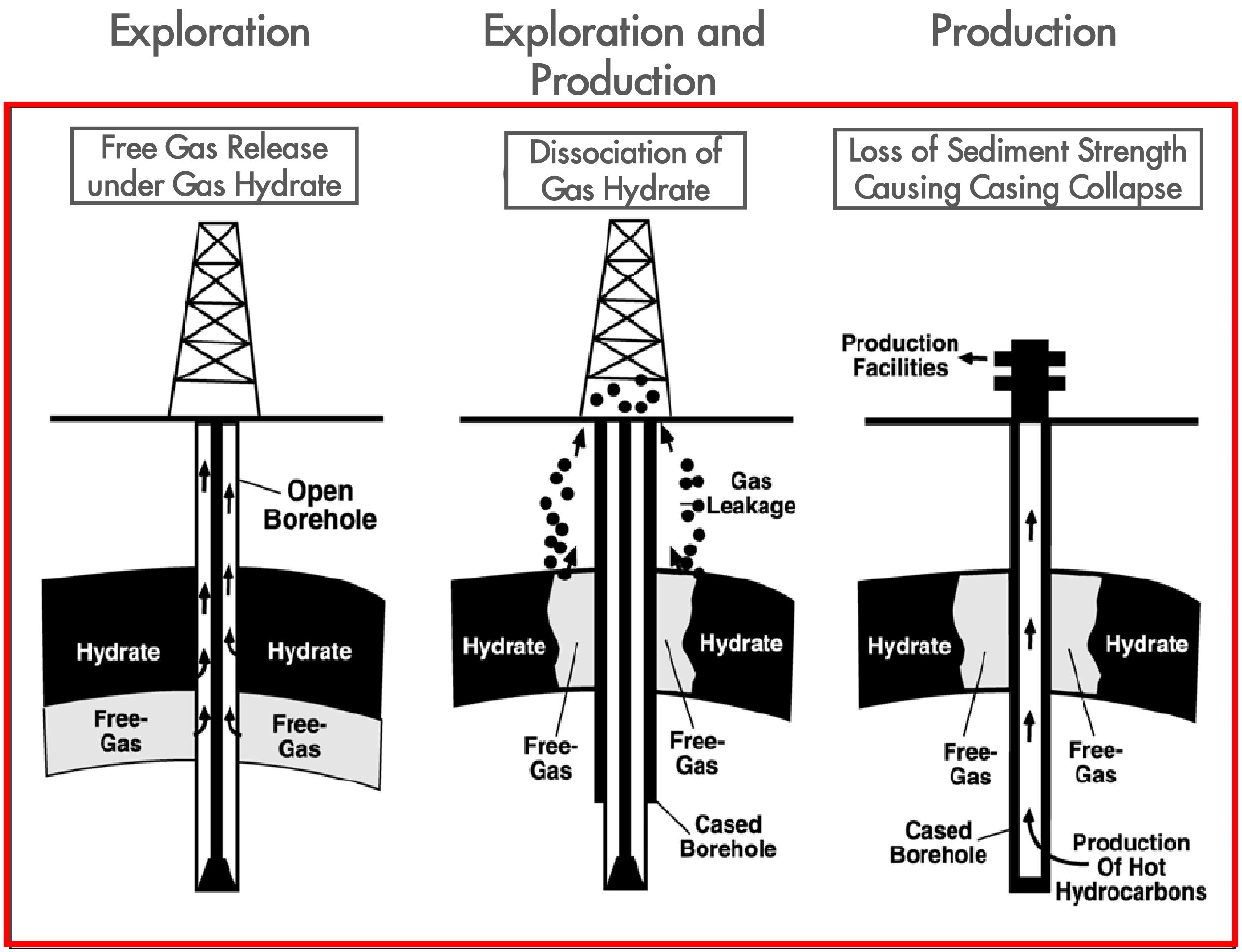
Act as Glide Plan for Mass Failure



Early Literature of the1970's and 1980's

(from McIver,1982)

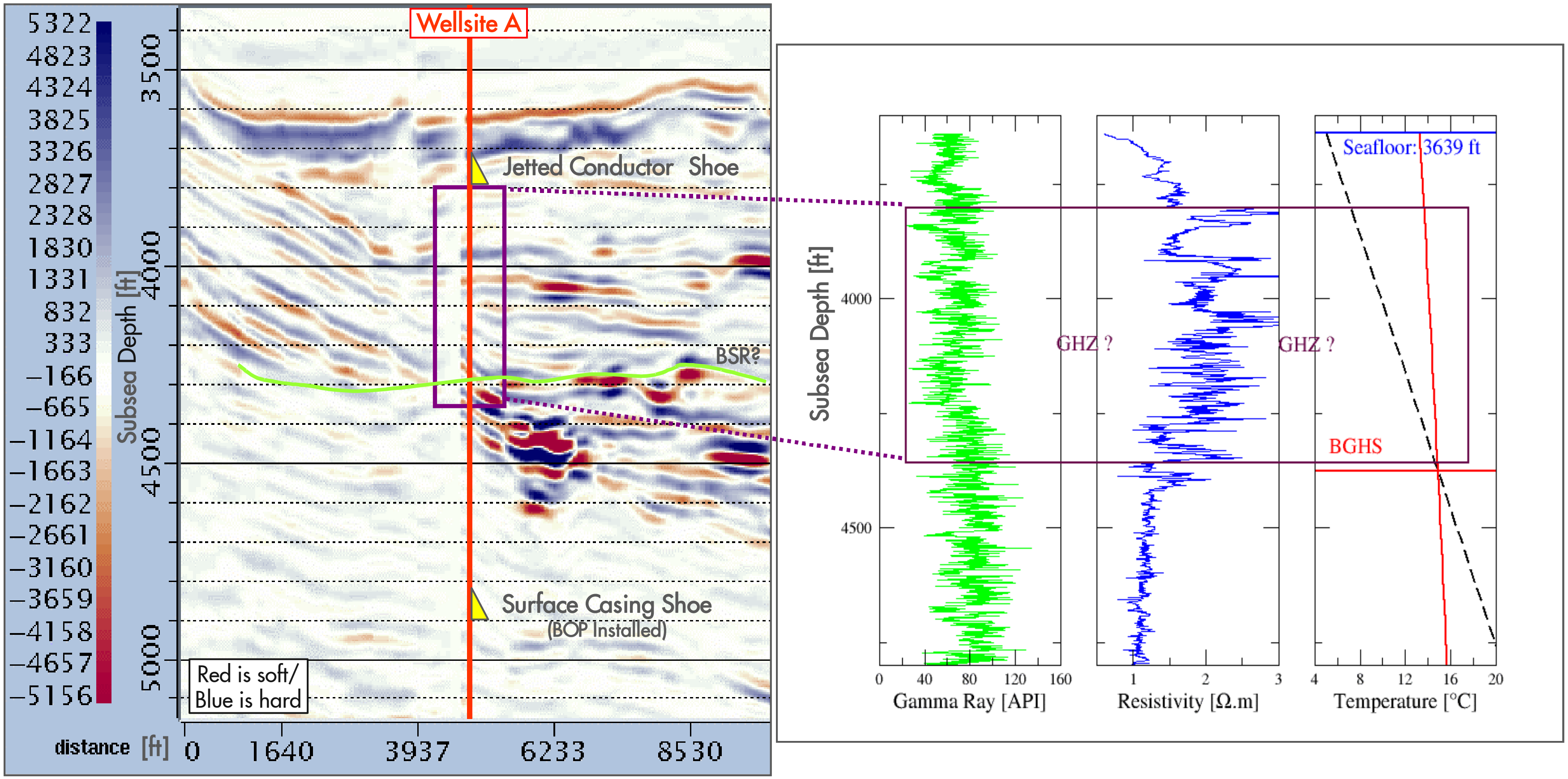
Summary of Potential Geohazard Issues Encountered



Mostly Early 2000's

(modified from Collett and Dallimore , 2002)

Example of Subsurface Gas-hydrate Occurrence



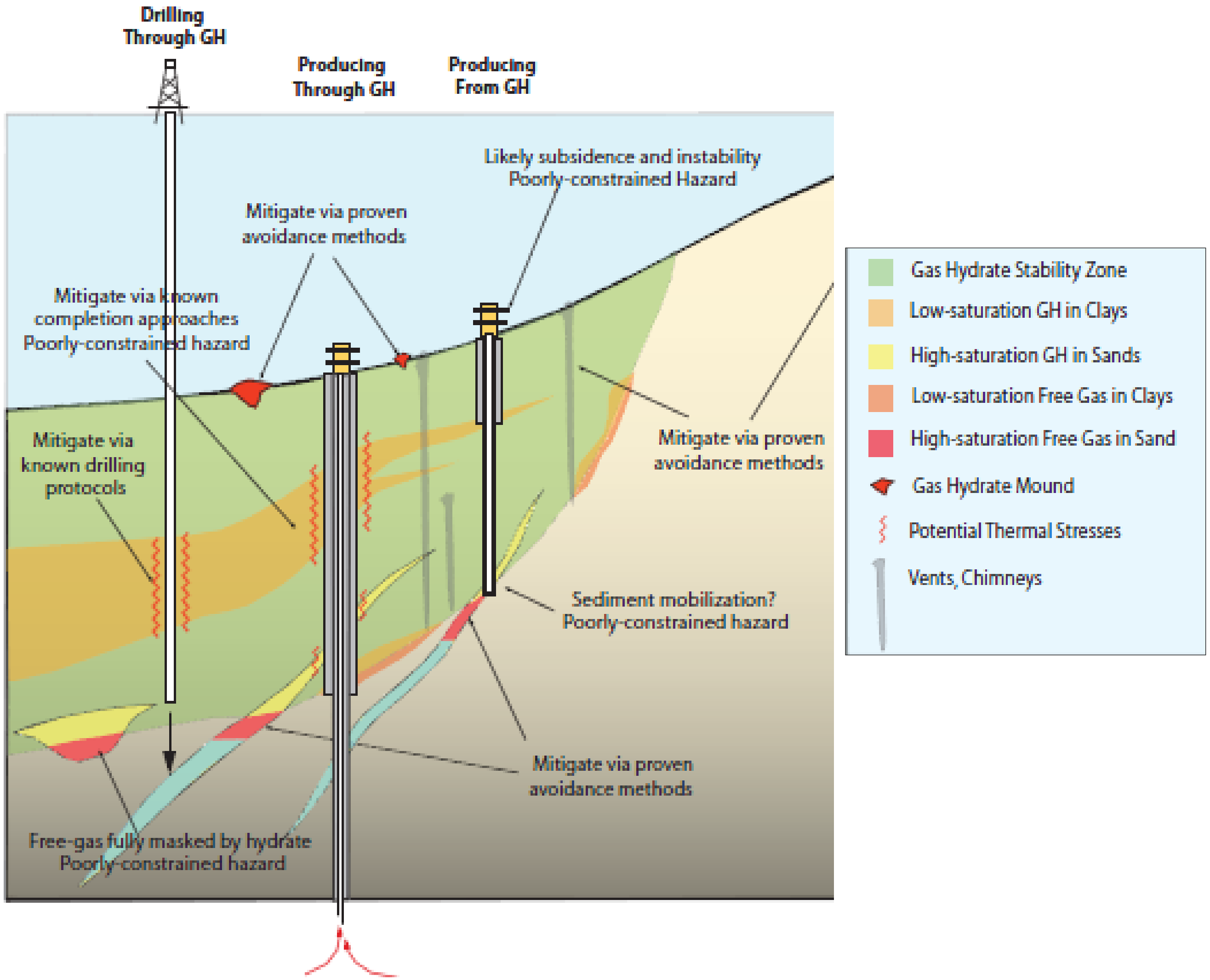
Mid to late 2000's

(from Nimblett et al., 2005)

Presentation Outline

- Historical evolution of gas hydrate as a geohazard
- Potential *operational geohazards* related to gas hydrate
- Potential n*aturally occurring geohazards* related to gas hydrate
- Summary thoughts and questions

Potential Operational Gas-hydrate Geohazards in the Global Deepwater



Early 2010's

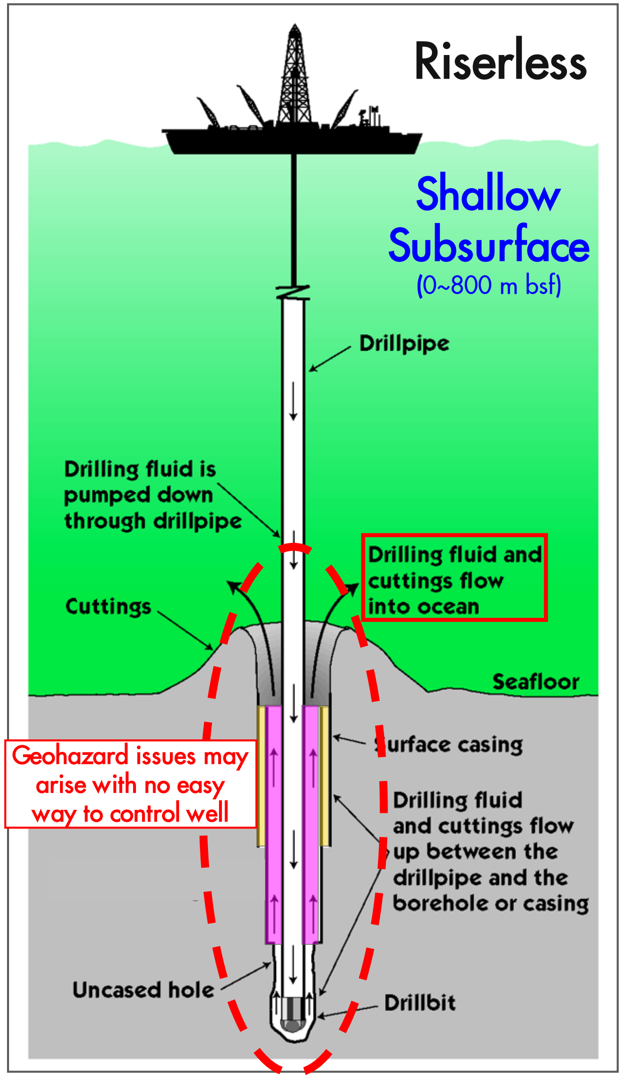
(modified from Boswell et al., 2012)

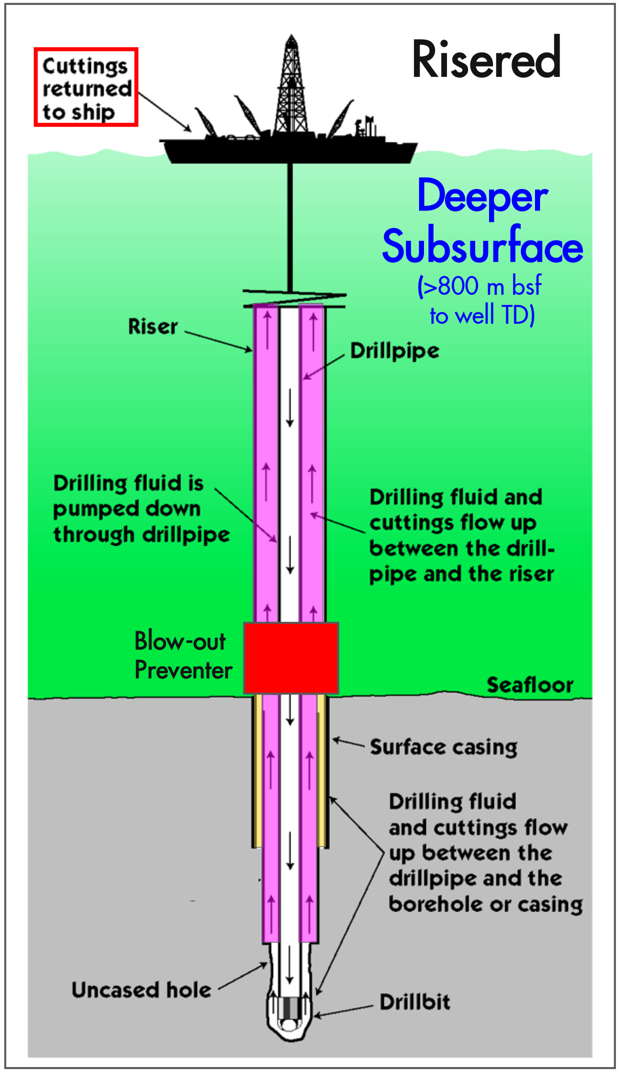
Historical Progression for the Understanding of Potential Operational Geohazard Issues

	Drilling Through Gas Hydrates	Drilling To Gas Hydrates
Production	• Only a few examples exist, but trends are emerging • Means of mitigation are probably known, but could be very expensive	• Little actual experience yet, only short production tests to date • Still don't know what we don't know!
Exploration	• Much anecdotal experience, but most information remains proprietary • Generally not many serious pro-blems, but nagging issues persist	• Focus of substantial scientific drilling effort for the last two decades • Only a few issues to date, but still more to learn

Exploration – Drilling Through Gas Hydrate

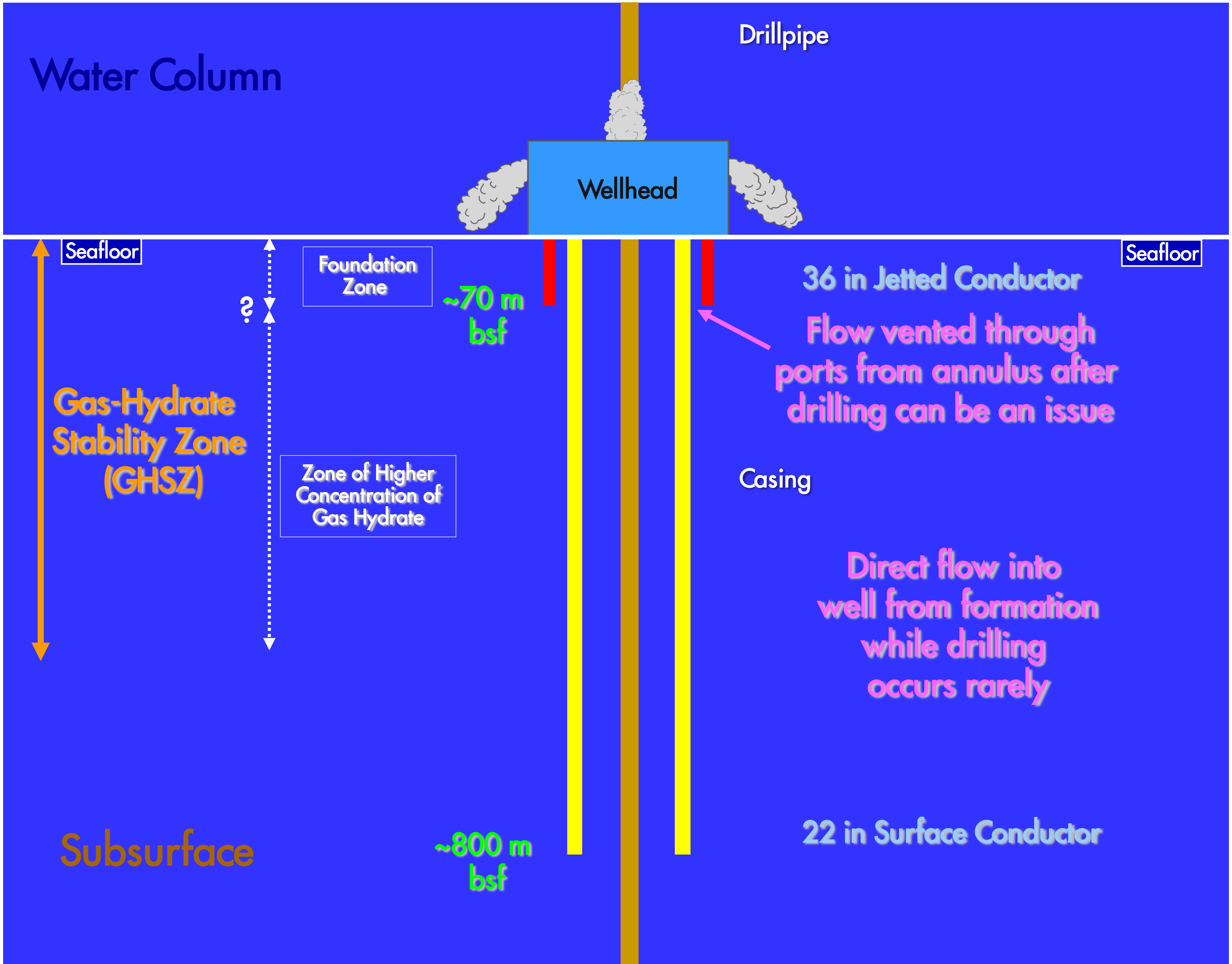
What Is Riserless Drilling?





(modified from Sawyer, 1996)

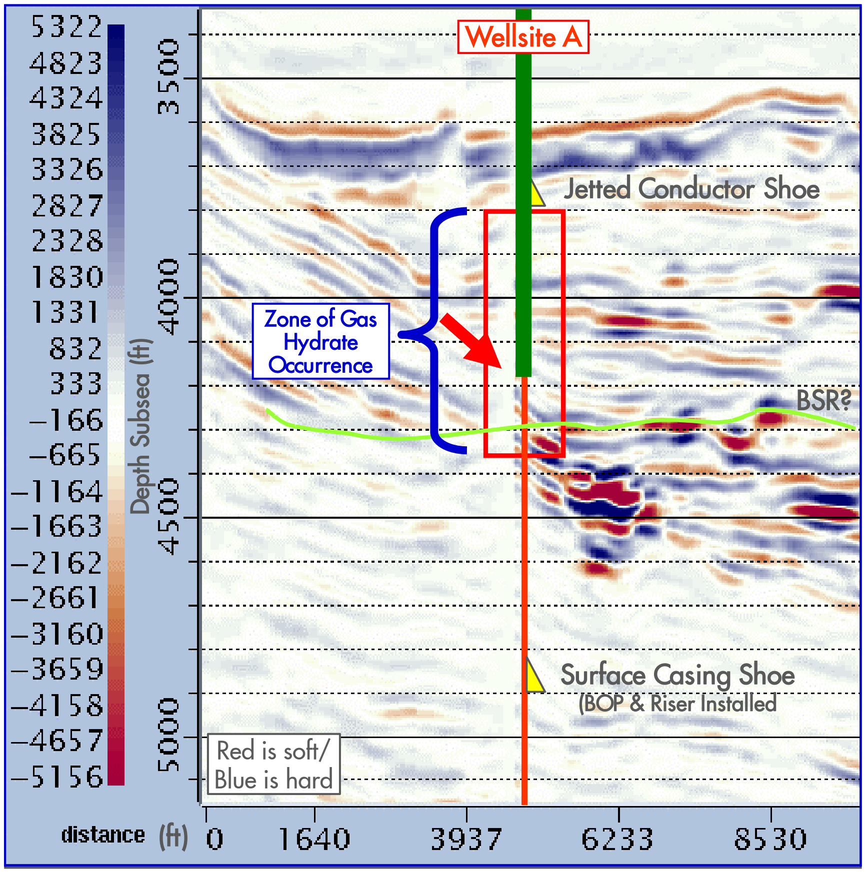
Gas Hydrate and Riserless Casing Scheme



Flow from Wellhead Ports

Response to Penetrating Gas-hydrate Interval in a "Typical" Deepwater Well – TIME 1

1- Drilling of Gas-Hydrate Interval in Riserless Section of Well

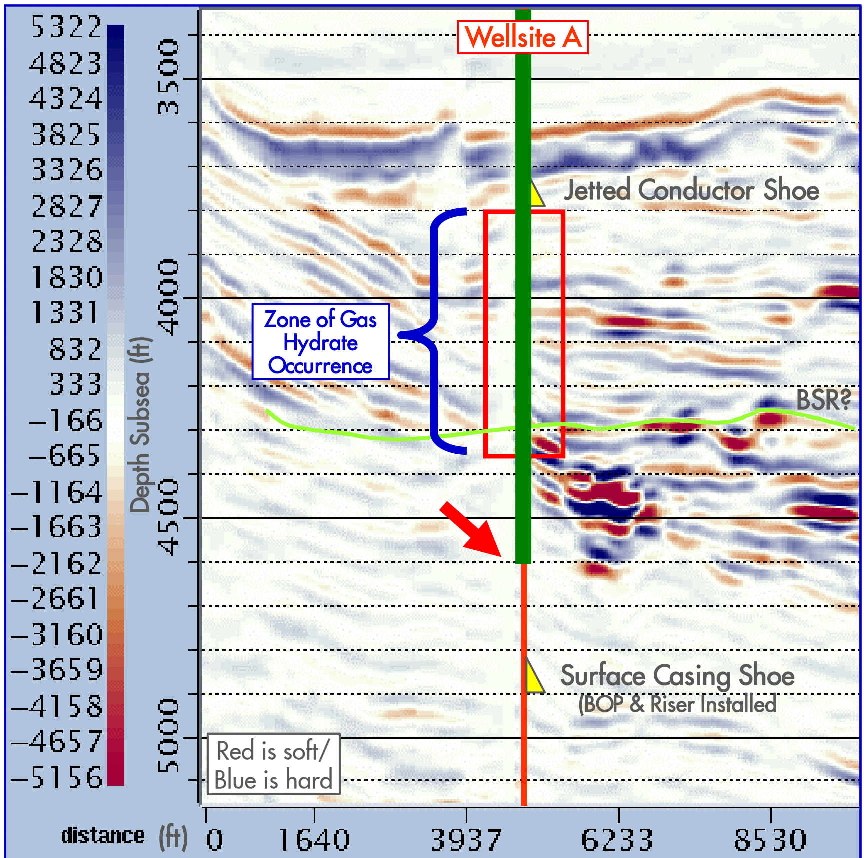


- During penetration of gas hydrate interval moderately low to slight gas flow out of wellhead ports is noted on the connection of each stand of drillpipe (~30 m length).

(image from Nimblett et al., 2005)

Response to Penetrating Gas-hydrate Interval in a "Typical" Deepwater Well – TIME 2

2 - Drilling below Gas Hydrate Interval in Riserless Section of Well

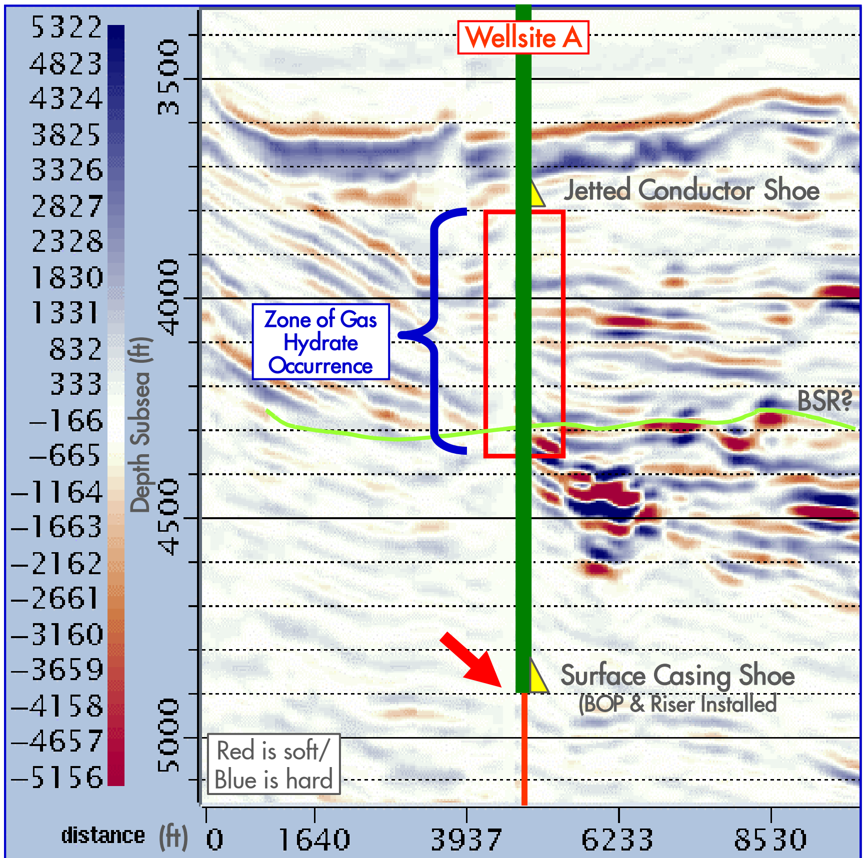


- During penetration of gas hydrate interval moderately low to slight gas flow out of wellhead ports is noted on the connection of each stand of drillpipe (~30 m length).
- Below gas hydrate interval, gas flow out of wellhead ports at each stand connection will either continue or may even stop.

(image from Nimblett et al., 2005)

Response to Penetrating Gas-hydrate Interval in a "Typical" Deepwater Well – TIME 3

3 - TD of Riserless Section of Well, Running Casing, Cementing, and Installing BOP/Riser

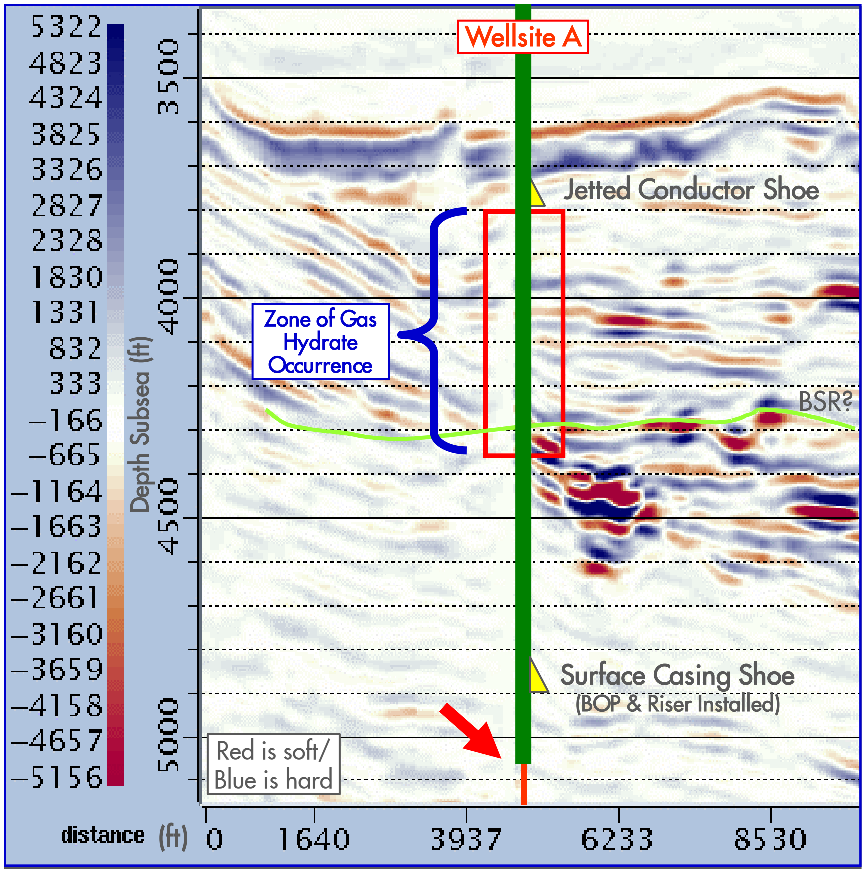


- During penetration of gas hydrate interval moderately low to slight gas flow out of wellhead ports is noted on the connection of each stand of drillpipe (~30 m length).
- Below gas hydrate interval, gas flow out of wellhead ports at each stand connection will either continue or may even stop.
- Gas flow out of wellhead ports stops due to increased mud weight in preparation for running casing, cementing, and installing BOP/riser.

(image from Nimblett et al., 2005)

Response to Penetrating Gas-hydrate Interval in a "Typical" Deepwater Well – TIME 4

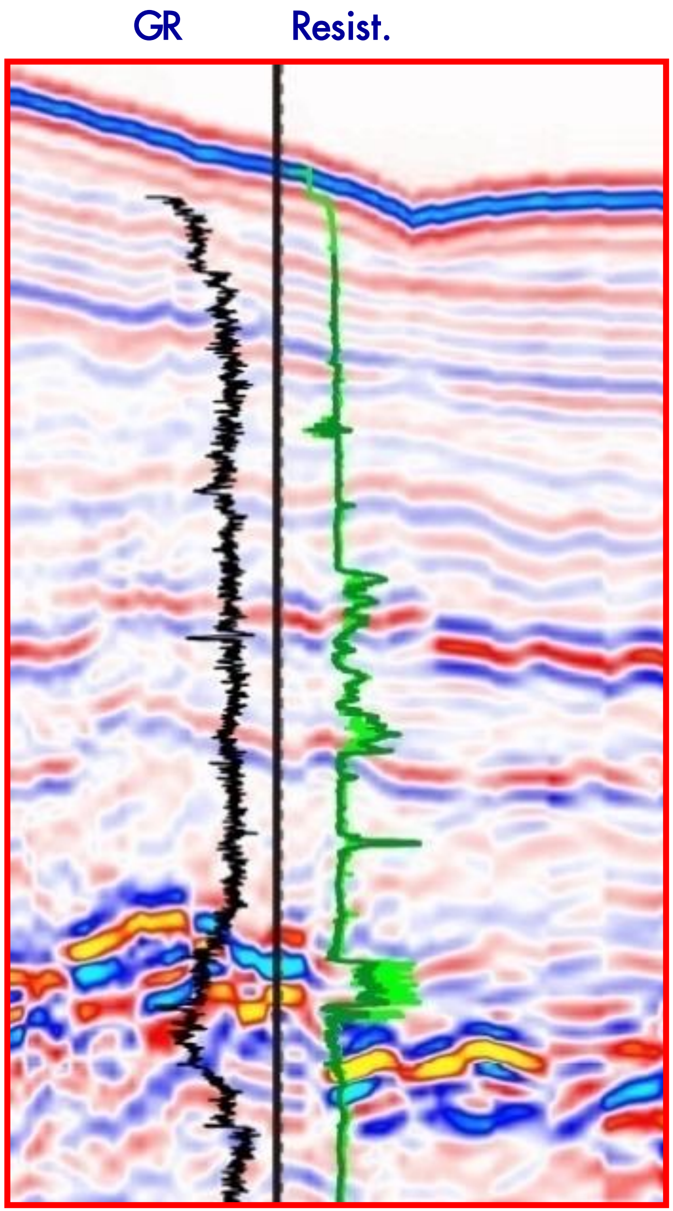
4 - Drilling into the Risered Section of Well after BOP and Riser Installed



- During penetration of gas hydrate interval moderately low to slight gas flow out of wellhead ports is noted on the connection of each stand of drillpipe (~30 m length).
- Below gas hydrate interval, gas flow out of wellhead ports at each stand connection will either continue or may even stop.
- Gas flow out of wellhead ports stops due to increased mud weight in preparation for running casing, cementing, and installing BOP/riser.
- After <u>3-5 days</u> of riserless section TD, drilling risered up into new formation, gas flow again observed out of wellhead port and may continue for the rest of the well.

Exploration – Drilling To Gas Hydrate

Scientific Drilling Targeting Gas Hydrate



Interpretation by McConnell - AOA and JIP Science Party

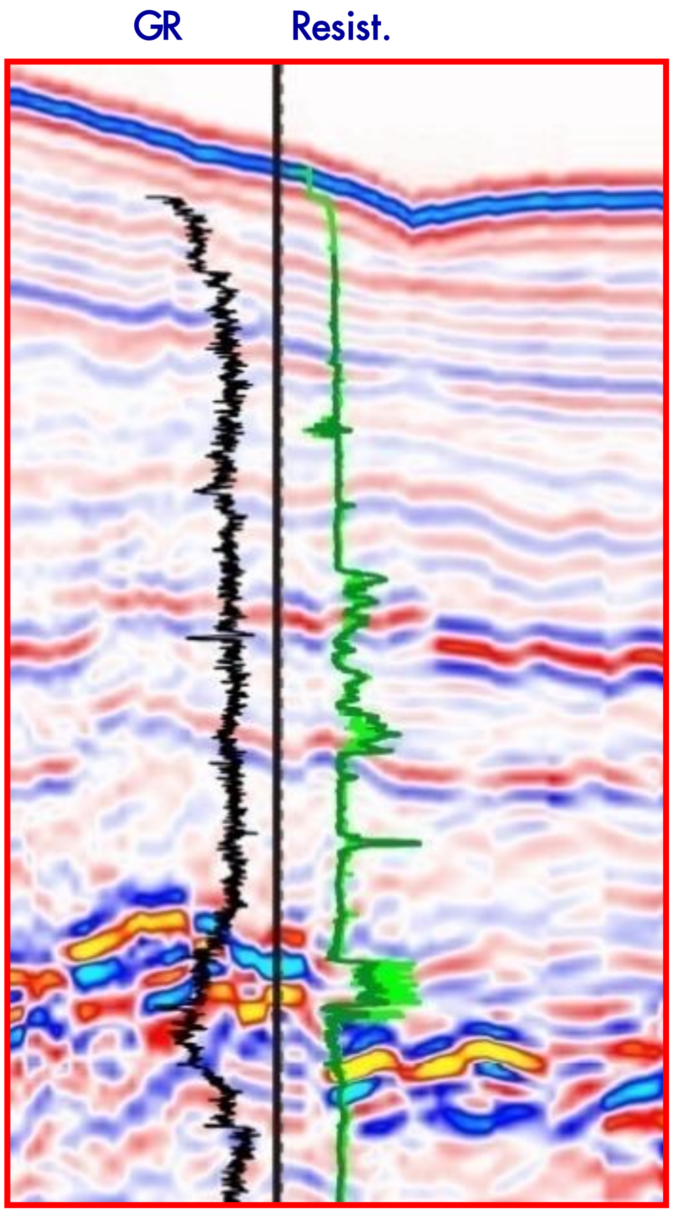
Chevron –DOE GOM Gas Hydrate JIP Leg II

Source – Dept of Energy Leg II Initial Reports

Fracture-Fill and Pore-Fill Gas Hydrate

~100 ft Gas Hydrate in Sand (no gas below)

Scientific Drilling Targeting Gas Hydrate

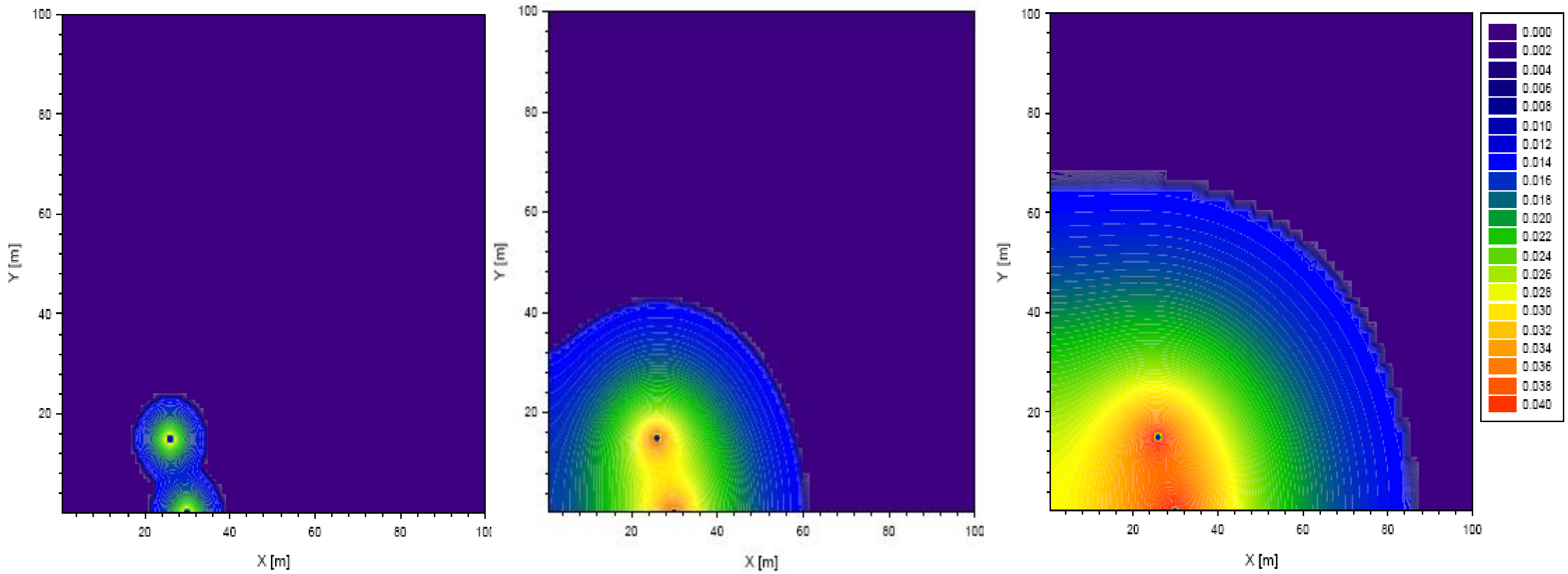


- Nothing unusual about the geohazards issues encountered.
- Typical geohazard issues were shallow water flow and wellbore instability.
- Again, the gas hydrate intervals (two distinct types) were not a particular geohazard concern.
- Borehole actually has more stability in gas-hydrate interval, than in gas-hydrate free interval!!

Production – Drilling Through Gas Hydrate

Modeling Movement of Dissociation Front at a Well Cluster for Field Development

Dissociation Front after 1 Year | Dissociation Front after 10 Years | Dissociation Front after 30 Years



- Fracturing displaces soil and loads wells
- Fractures propagate to nearby facilities
- Potential displacement of subsea equipment

(from Hadley et al., 2008 and Peter et al., 2008)

Historical Progression for the Understanding of Potential Operational Geohazard Issues

	Drilling <u>Through</u> Gas Hydrates	Drilling <u>To</u> Gas Hydrates
Production	• Only a few examples exist, but trends are emerging • Means of mitigation are probably known, but could be very expensive	• Little actual experience yet, only short production tests to date • Still don't know what we don't know!
Exploration	• Much anecdotal experience, but most information remains proprietary • Generally not many serious problems, but nagging issues persist	• Focus of substantial scientific drilling effort for the last two decades • Only a few issues to date, but still more to learn

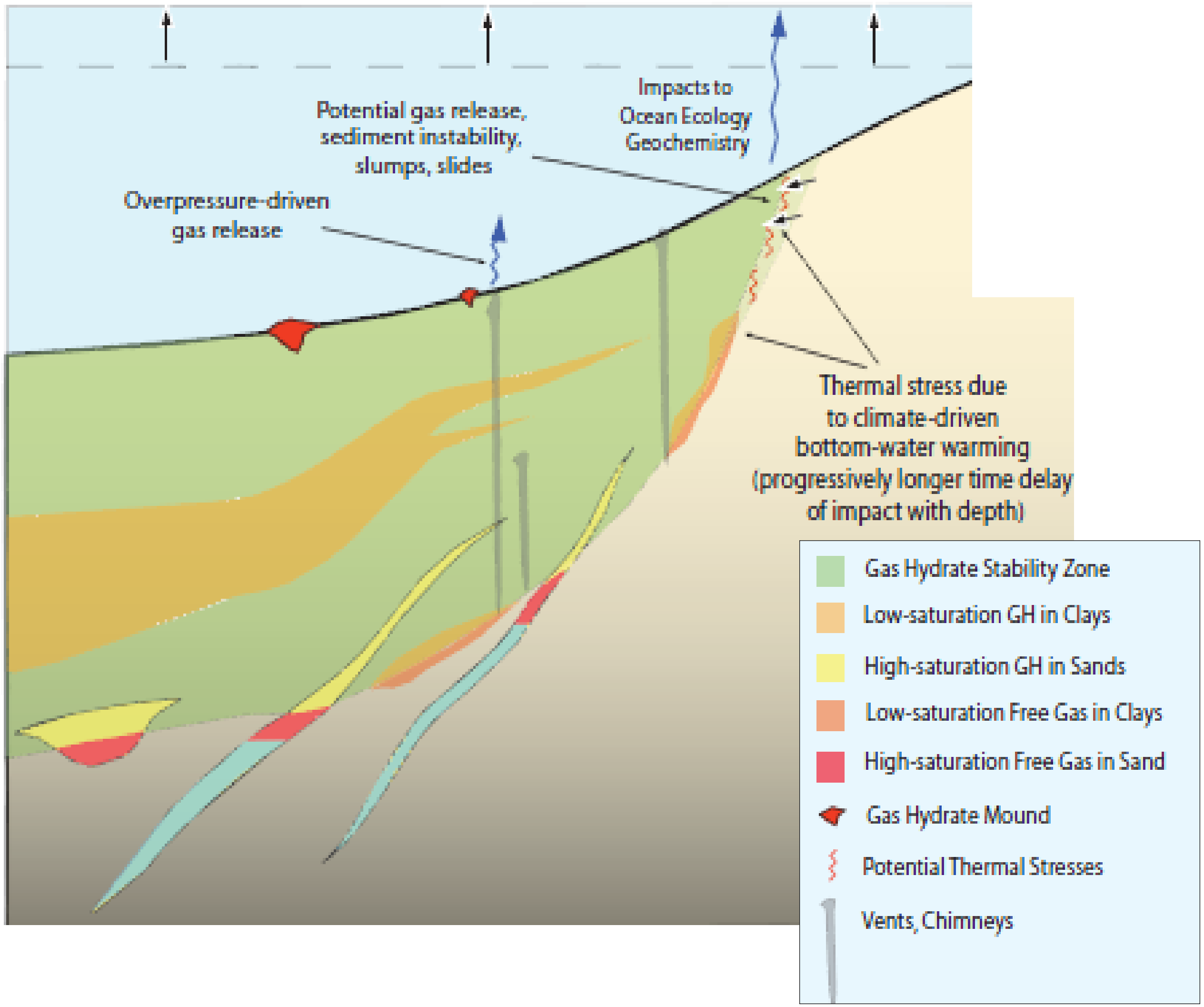
Potential Geohazards with Gas Hydrate as the Reservoir

- Flow assurance in gas-hydrate wells:
  - Sand control in reservoirs
  - Overall borehole stability
  - Formation of "uphole" gas hydrate
- Unintended degassing of methane from gas-hydrate reservoirs:
  - Flow behind pipe
  - Fracture formation
  - Breakthrough after dissociation
- Seafloor subsidence due to gas hydrate withdrawal
- Maintaining production casing integrity with change in sediment character as gas hydrate dissociates
- Management of excess water from gas-hydrate dissociation

Presentation Outline

- Historical evolution of gas hydrate as a geohazard
- Potential *operational geohazards* related to gas hydrate
- Potential *naturally occurring geohazards* related to gas hydrate
- Summary thoughts and questions

Potential Naturally Occurring Gas-hydrate Geohazards in the Global Deepwater



Early 2010's

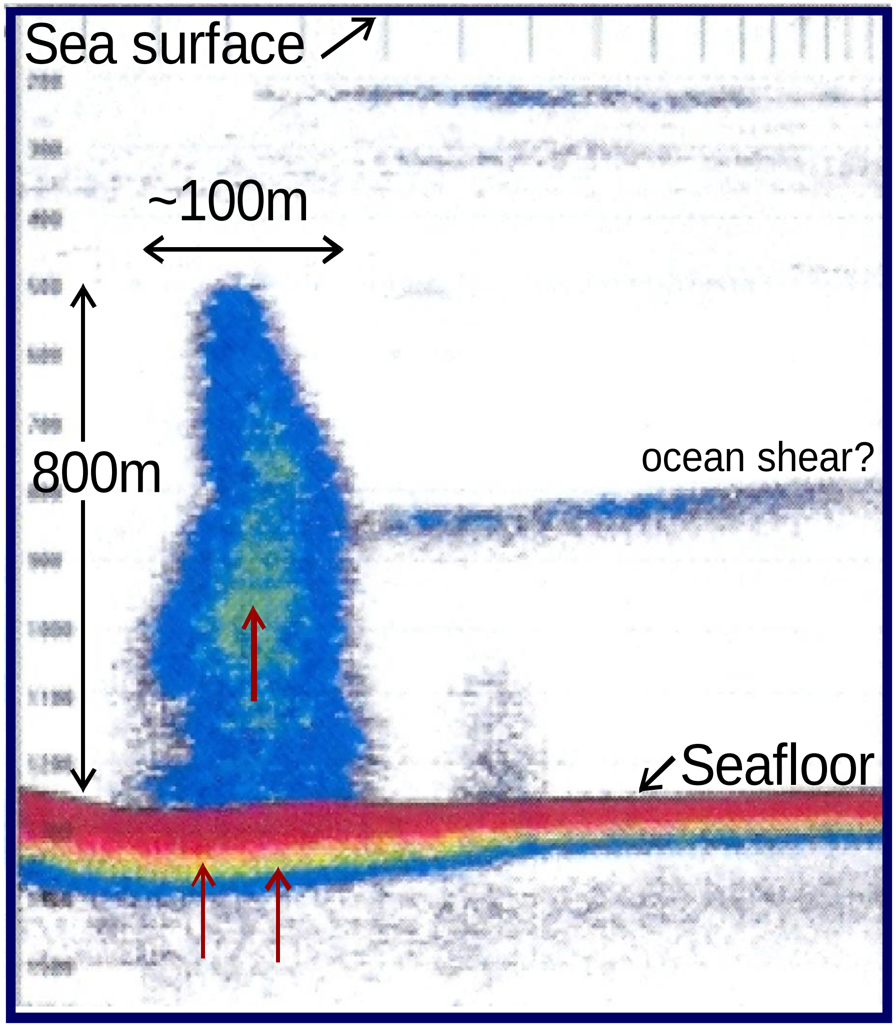
(modified from Boswell et al., 2012)

Types of Potential Naturally Occurring Gas-hydrate Geohazards

- Substantive release of methane gas caused by gas-hydrate dissociation
- Slope instability caused by mass failure due to gas hydrate-dissociation
- Subsurface gas chimneys that lead to cold vents on seafloor

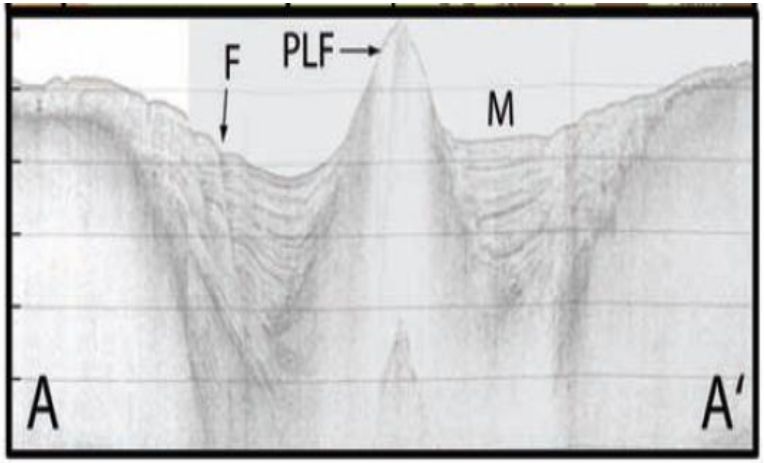
Substantive Release of Methane Gas

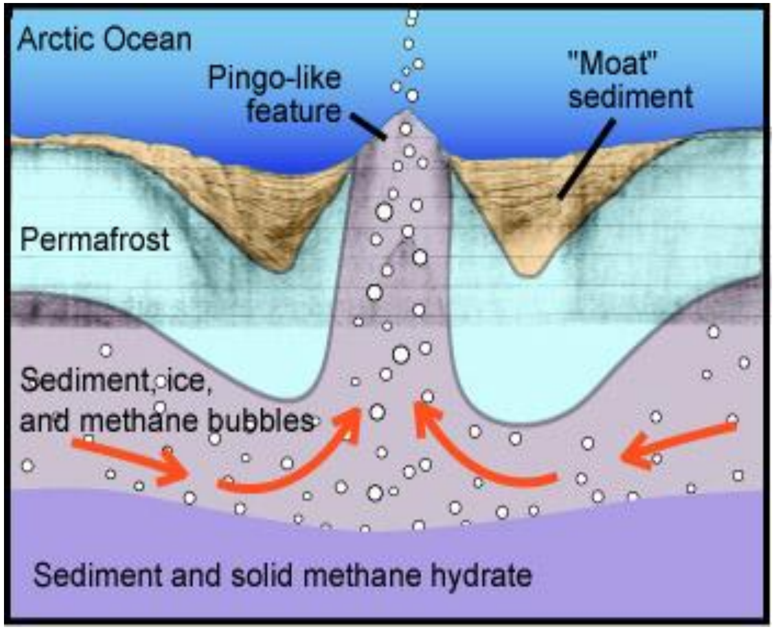
Documented Gas Release from the Seafloor



(courtesy of R. Hyndman, NRCan)

Pingo-Like Features (PLF)

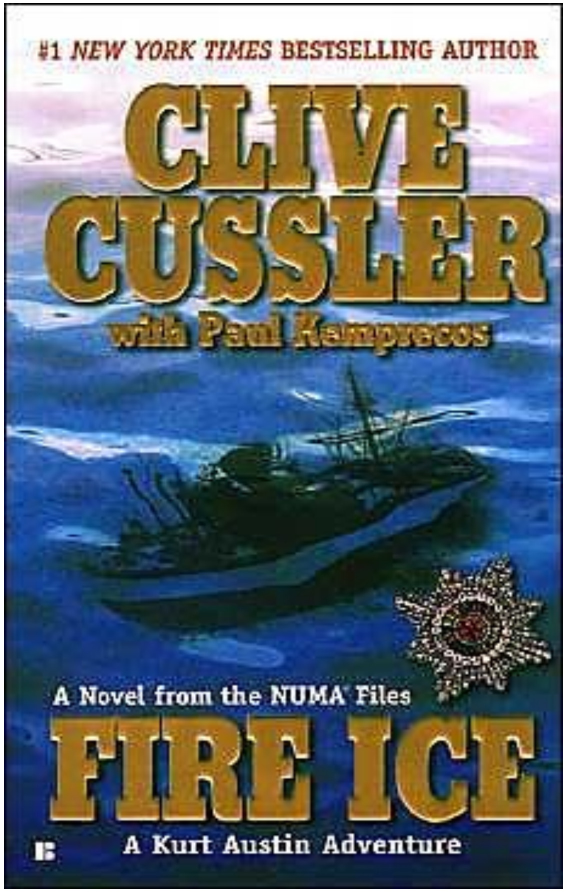




(from Paull et al., 2007)

Hyping Oceanic Methane Release by Mainstream Media

Nefarious Russian plot to melt all the gas hydrate on the U.S. eastern continental slope to gas major population centers along Eastern Seaboard



Marine methane explosions through time cause global disasters

… And Even More Hyping in Online Blogs!

ARMAGEDDON ONLINE.ORG

Methane Explosion

At the ocean floor lies a sleeping monster, one that millions of years ago devastated the Earth, causing a mass-extinction, and today could be released again. It is silent, invisible and deadly, and contains double the energy of the entire world's fossil fuels combined. It is the frozen methane reserves at the bottom of the sea; capable of causing massive rises in global temperatures and igniting the atmosphere.

atmosphere: global temperatures rose by 13 degrees Fahrenheit, melting the ice caps and forcing many species to extinction. 80% of all deep-sea creatures became extinct, and there were severe consequences for land animals. If vast amounts of methane were released, the highly explosive gas would be ignited by lightning, scorching huge area in a fiery hell-on-earth.

What is methane?
Methane is an extremely flammable and explosive gas. At the bottom of the ocean it is found in a form called 'methane hydrate', when the particles are locked in a lattice with water. When this melts, it releases methane gas with 160 times this volume. Methane hydrate is found deep in the oceans, more than 350m down. It is estimated that there is more than 200,000 trillion cubic feet of this gas at the bottom of the ocean; 80,000 times conventional natural gas reserves.

How is it released?
Small bursts of methane hydrate can be released by sudden events that break the lattice, such as landslides and earthquakes on the ocean floor. This releases a large amount of methane from the local area. This has been suggested as a possible explanation for the Bermuda Triangle - an area of ocean in the South Atlantic where dozens of ships and planes have disappeared without trace. The theory goes that landslides release the methane, which explodes on contact with, for example, a plane's engines. This shows how dangerous even small bursts can be.

It would take a bigger event than an earthquake or landslide to start releasing vast quantities of methane hydrate. The current fear is that global warming would increase the ocean temperature to the point where frozen methane starts to melt all over the world.

What would be the effects if the gas was released?
If a large proportion of the gas were released the effects would be devastating. If hundreds of thousands of trillions of tons were released into the atmosphere, the rate global warming would skyrocket. Methane is 20 times more powerful a gas at raising global temperatures than carbon dioxide, so a release of a vast quantity of gas would cause huge temperature rises around the world. If temperatures rose by the 13 degrees Fahrenheit they did during the last release, ice caps would start to melt flooding large areas of the Earth. Worse, the gas would be ignited by lightning, leaving huge fires over areas of land, with coastal areas at especially great risk of destruction. Many cities that escaped the rising sea levels would not be spared the fire.

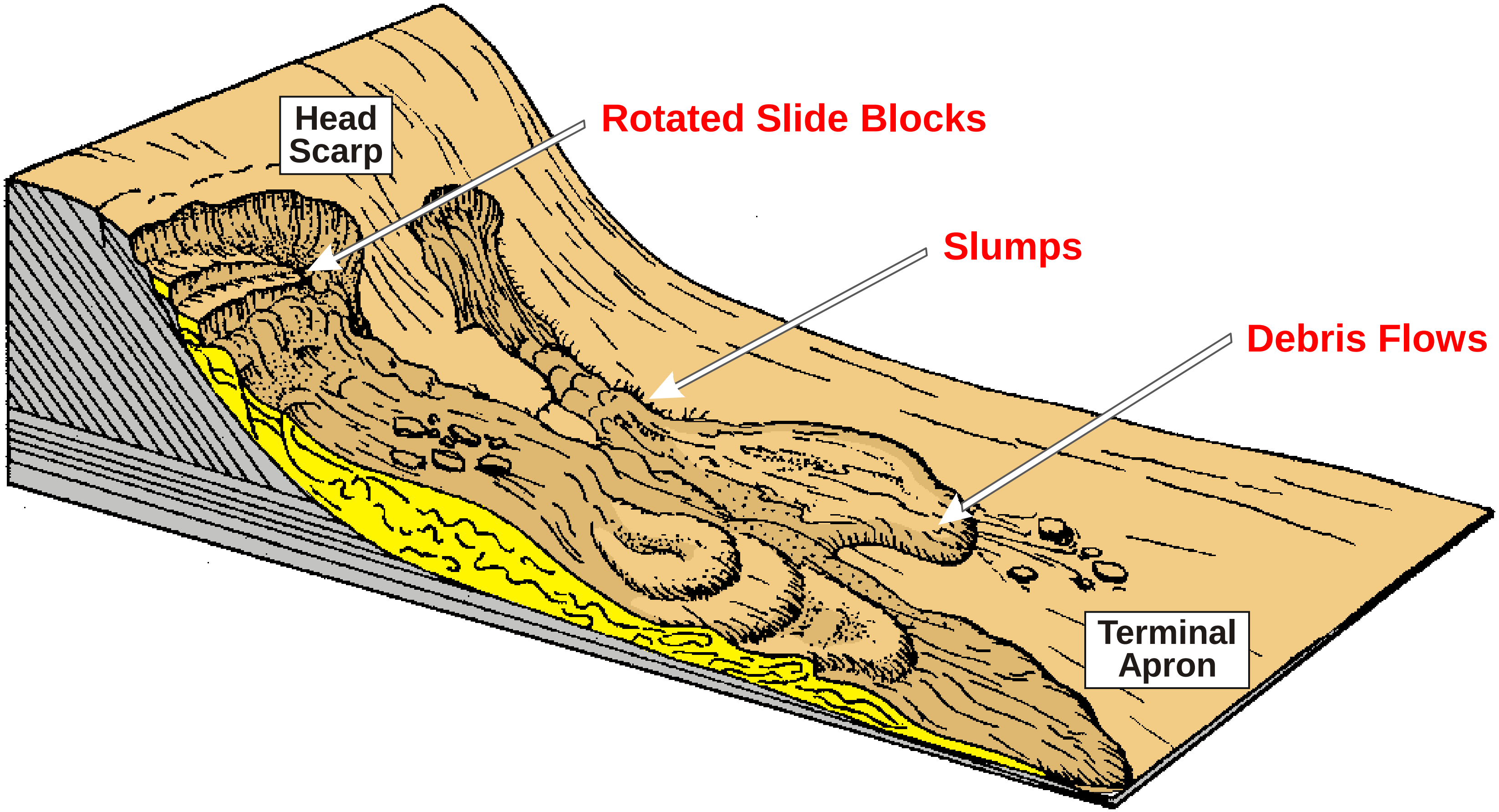
Contrary Evidence to Massive Methane Release from Gas Hydrate in the Holocene

- Isotopic studies of methane in ice cores suggest that the contribution of gas hydrate to the atmosphere may have been minor (Sowers, 2006)

- Budget calculations for the global carbon cycle suggest that the input of methane from the oceans (e.g., from gas hydrate) also may be minimal (Maslin and Thomas, 2003)

- Melting of gas hydrate occurs very slowly over a long time period (Sultan, 2007)

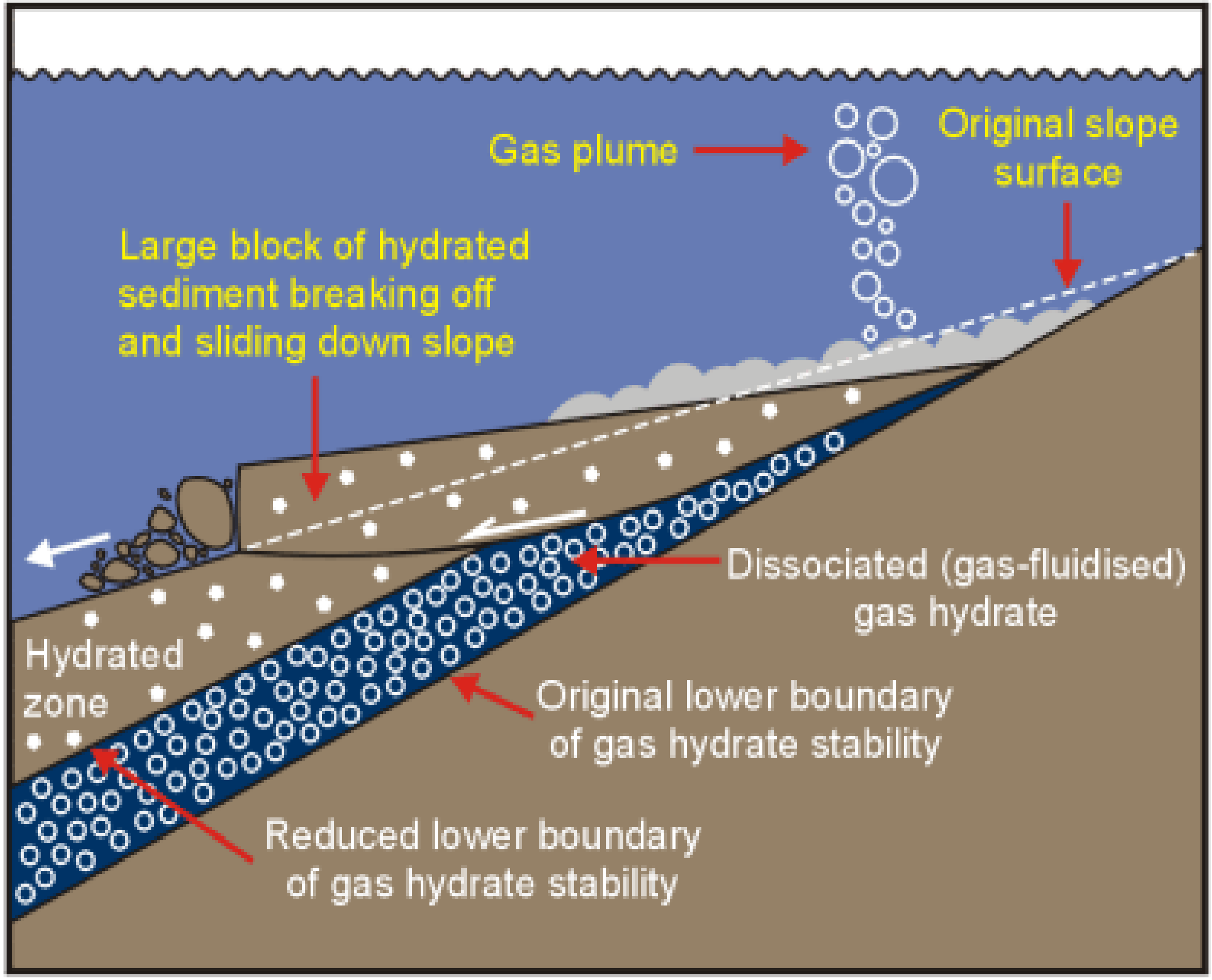
Typical Mass Failure



Note: Now commonly called mass-transport deposits (MTDs)

(modified from Galloway and Hobday, 1996)

Mechanism of Gas-hydrate Dissociation



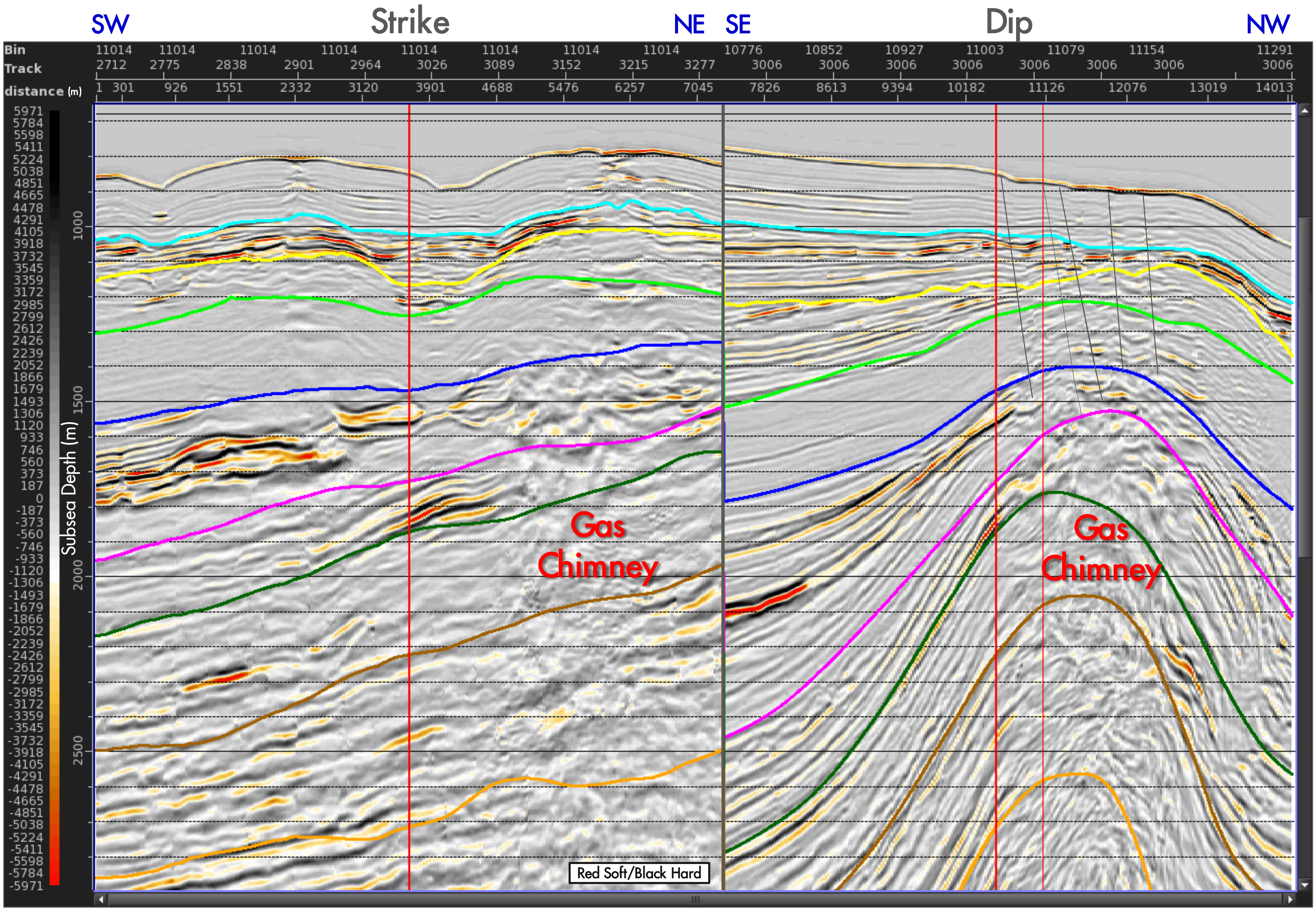
(modified from McIver,1982)

Lack of Evidence for Gas-hydrate Induced Mass Failure

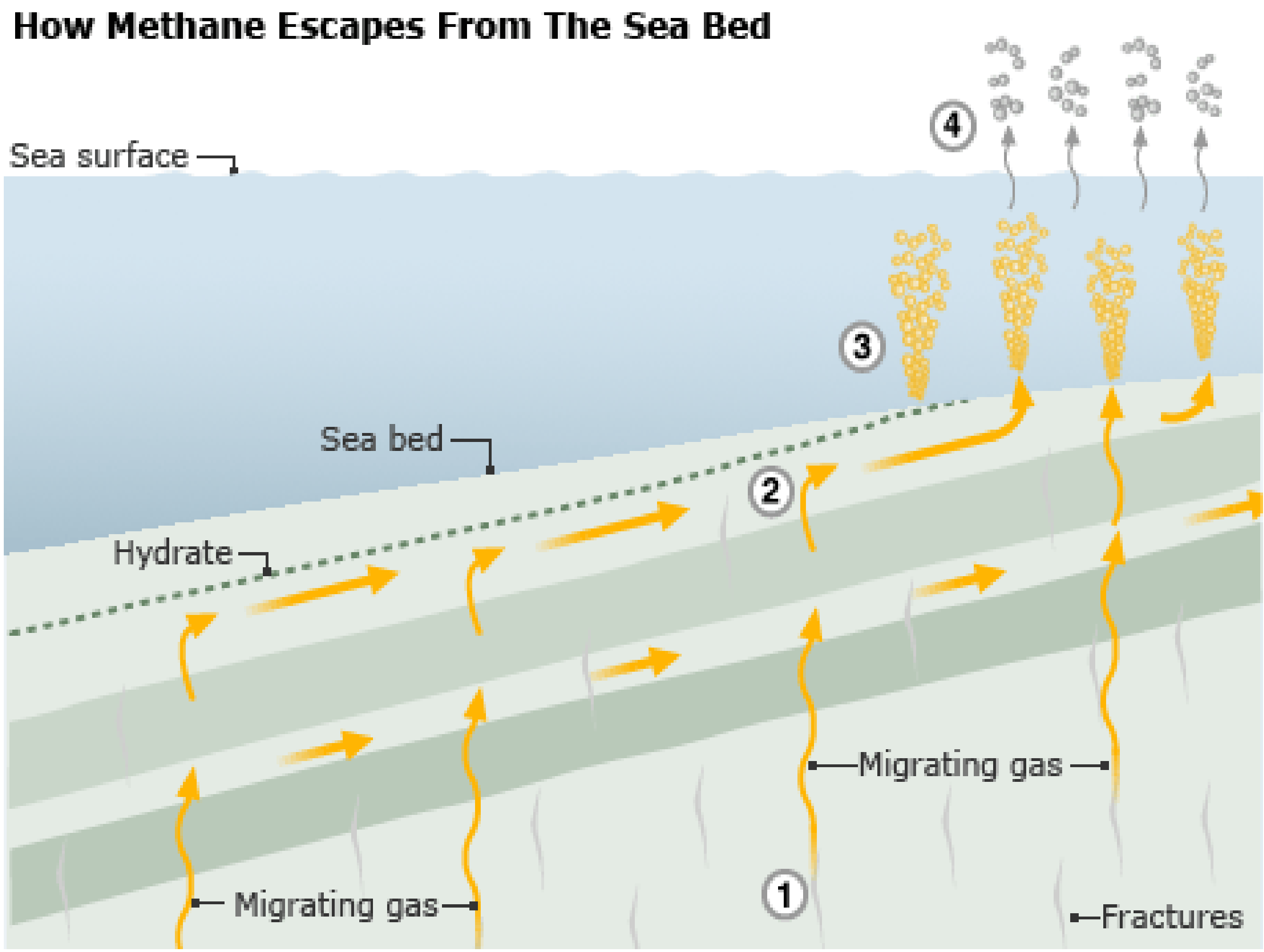
- No conclusive evidence linking mass failure to gas hydrate dissociation over geologic time – though much has been published.
- Little evidence of gas-hydrate related mass failure during the Holocene.
- Limited documentation for substantial recent mass failure on any continental margin - certainly no evidence relating sediment failure to gas-hydrate dissociation.
- Distribution of gas hydrate seldom coincides with initial glide plane along which the deposit subsequently slides.
- Marine sediments are generally somewhat permeable, so gas hydrate dissociation may actually displace fluids and not allow *in situ* pressure to increase.

Gas Chimneys

Typical Gas Chimneys Found In Many Basins Globally



Cartoon of Gas Escape



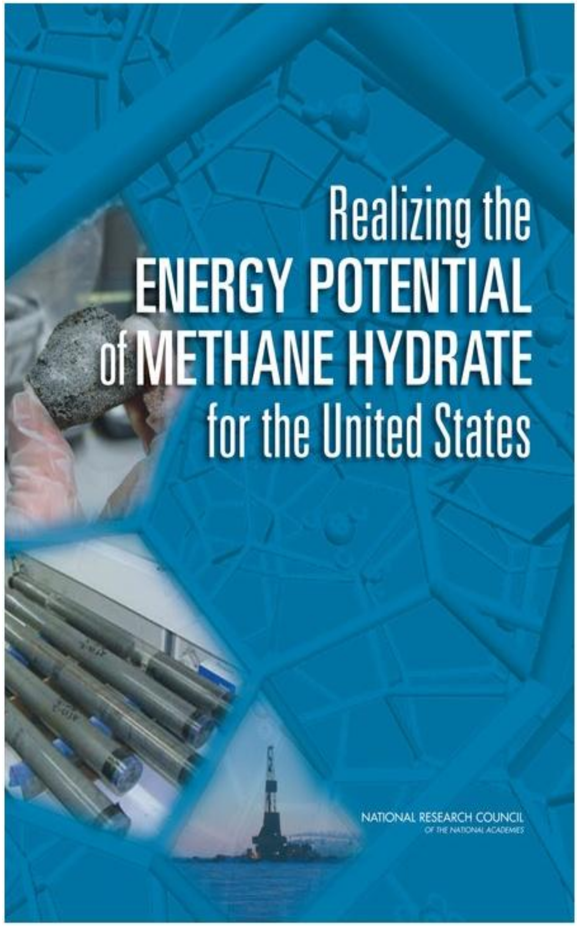
(from BBC, 2009)

Presentation Outline

- Historical evolution of gas hydrate as a geohazard
- Potential *operational geohazards* related to gas hydrate
- Potential *naturally occurring geohazards* related to gas hydrate
- Summary thoughts and questions

U.S. National Research Council (NRC) Report

Realizing the Energy Potential of Methane Hydrate
for the United States



150 pages (January 2010)

NRC Report Recommendations Translated!

- Compile industry experience drilling through and targeting gas hydrate.
- Organize forums to discuss these issues – yep, more gas-hydrate meetings!!!!
- Address potential geohazards related to gas-hydrate production by conducting focused basic research, including:
  - Field studies
  - Laboratory studies
  - Modeling studies

National Energy Technology Laboratory of the U.S. DoE

Marine Methane Hydrate Field Research Plan

60 pages (December 2013)

Summary Thoughts

- Drilling of gas hydrate is a manageable, but potentially expensive issue!
- Substantial information exists about the drilling of gas hydrate intervals, but much of this experience still is anecdotal and/or proprietary.
- There is a broad public awareness of spectacular and catastrophic marine processes that are not the key geohazard issues concerning producing gas-hydrate reservoirs.
- In part, we can use this increasing abundant information from industry drilling through gas hydrate and experience from scientific drilling targeting gas hydrate to frame the potential geohazards, associated with producing gas-hydrate reservoirs.
- A rapid increase in understanding of potential geohazards of gas-hydrate reservoirs will occur over the next few years as the number of gas-hydrate production tests increases.