USGS science for a changing world

Bluff geometry and material variability influence stress states relevant to coastal permafrost bluff failure

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The Arctic Coastal Erosion Problem

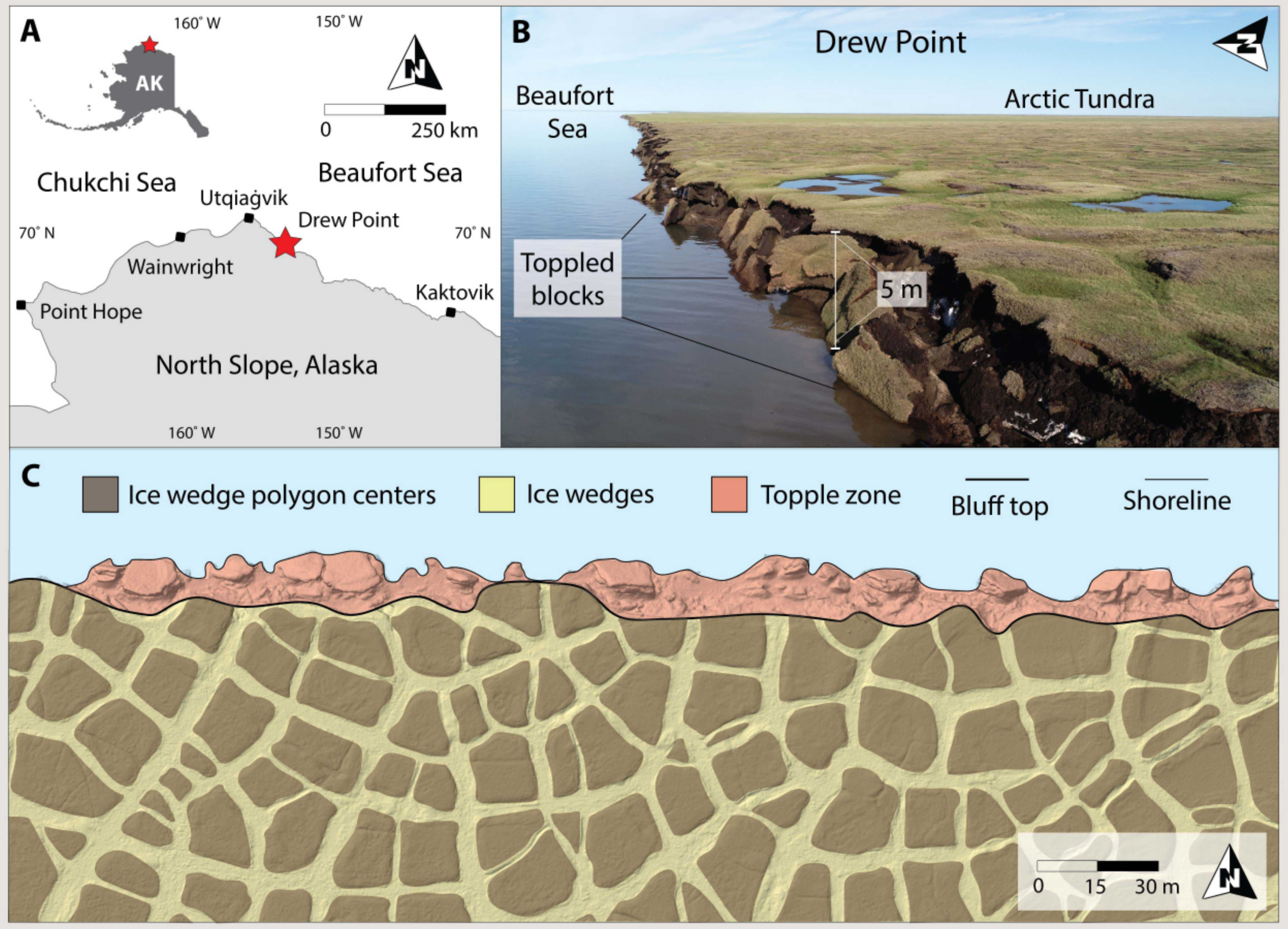
• Annual rates of erosion along ice-rich portions of the Arctic Alaskan coast have doubled since the middle of the 20th century and appear to be accelerating.

• Much of Arctic Alaska is inaccessible by all-season roads; therefore, people (e.g., Native villages) and infrastructure (e.g., strategic military assets, roads, and pipelines) are concentrated near the coast.

• The financial impact of enhanced coastal erosion will be further exacerbated by emerging geopolitical pressures, including the discovery of natural resources (e.g., hydrocarbons and minerals) and the opening of new shipping routes in the Arctic.

• Current engineering tools to plan for coastal erosion, largely developed for use in temperate climate zones that are dominated by non-cohesive sediments, are not applicable to the ice-bonded permafrost bluffs that are typical of Arctic Alaska.

Drew Point, Alaska



Bluff Failure

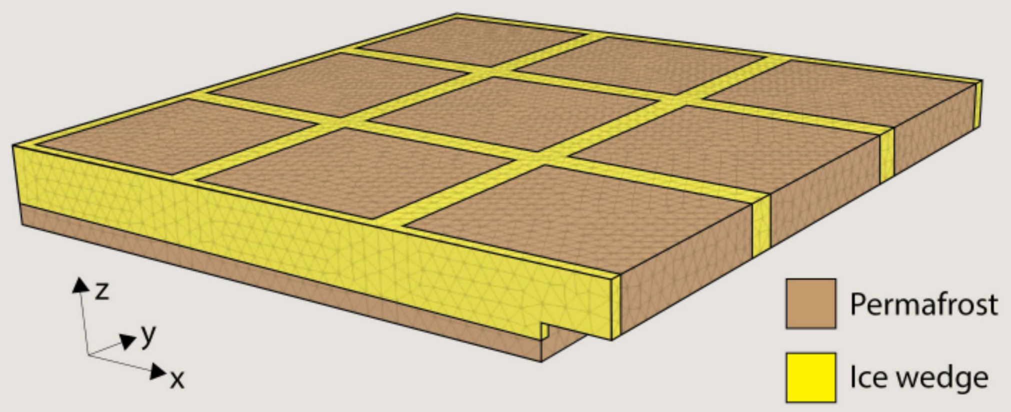
◀ Storms raise nearshore water levels and undercut the bluffs via thermo-abrasion until a toppling mode bluff failure occurs.

We applied continuum mechanics theory with simulations of elastic finite deformation to assess the impact of bluff geometry and material variability on stress states leading up to bluff failure. ▶

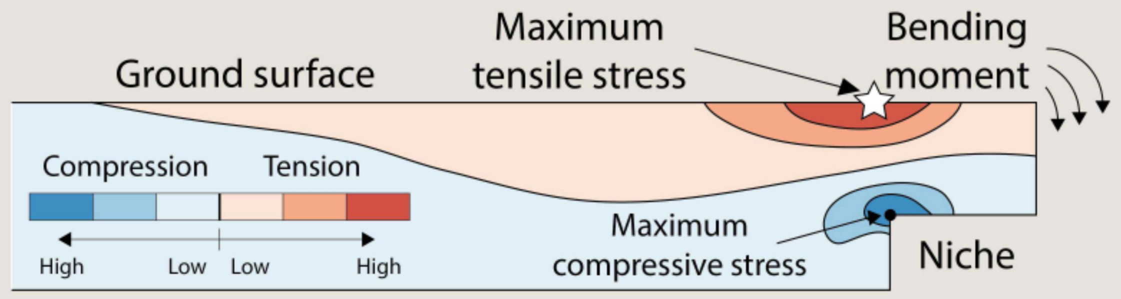
These simulations facilitated examination of stress patterns within the bluff and identification of the location and magnitude of the maximum tensile stress (σ_{Tmax}). ▶

Conceptual & Numerical Models

Physics-based simulations of stress and displacement

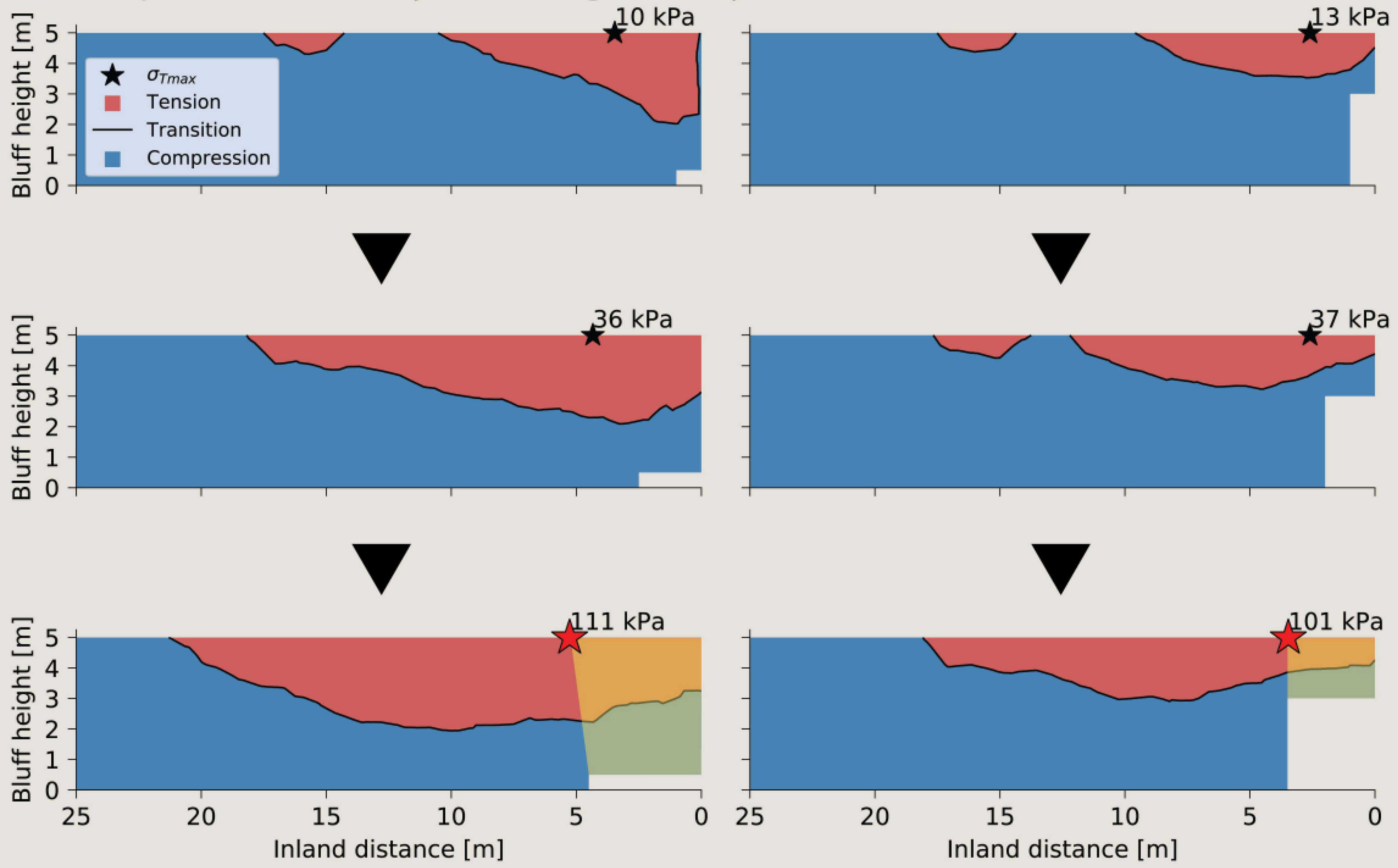


Cross-sectional view of the stress field



Identifying Potential Controls on Failure Characteristics

Impact of variability in niche geometry on stress field, cross sectional view

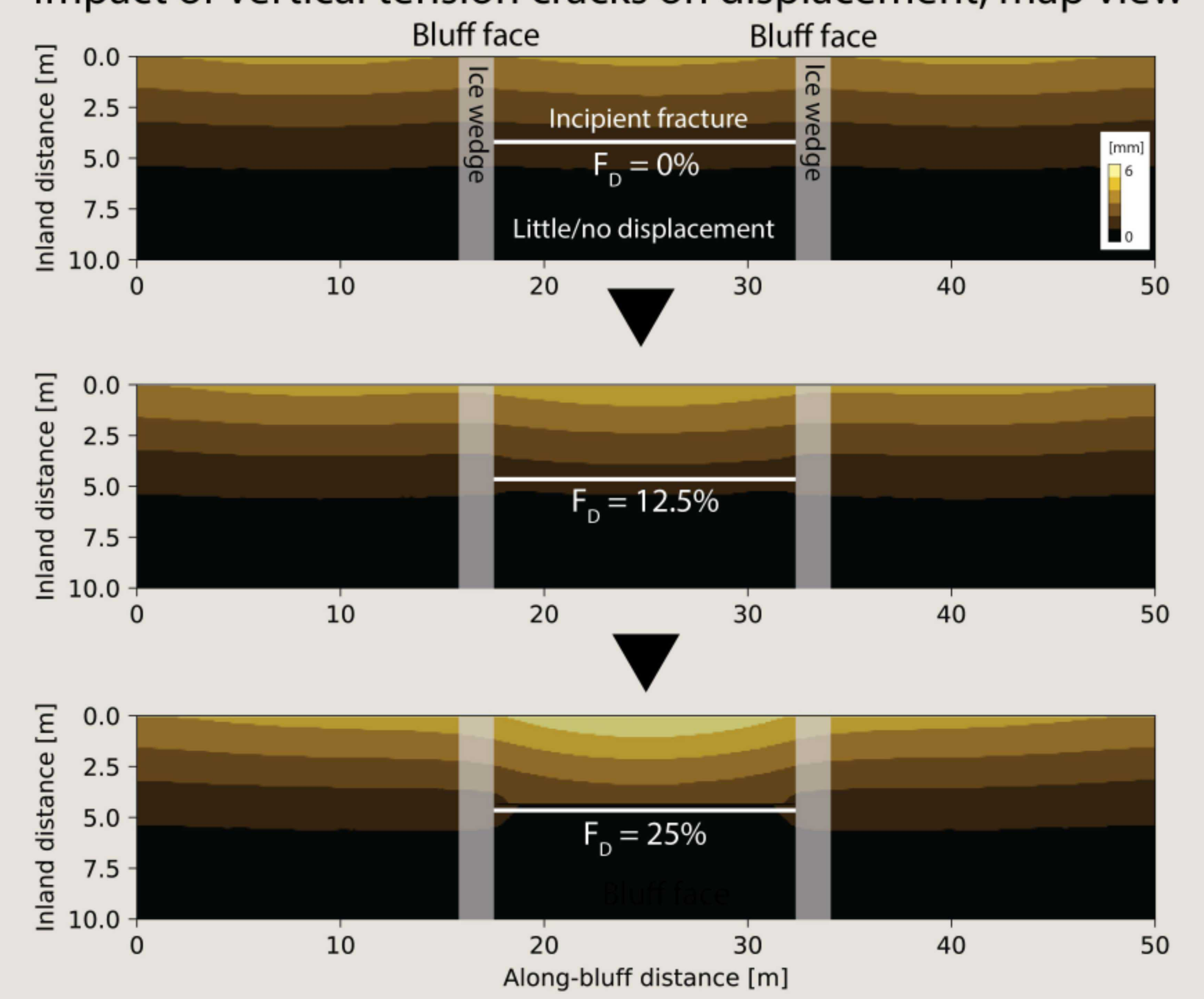


• Our geometric and material property simulation ensembles indicate that niche characteristics exert the largest impact on the location and magnitude of the σ_{Tmax}.

• End-member niche advancement scenarios reveal systematic differences in the patterns of stress, as well as the variability in the simulated σ_{Tmax}.

• **Takeaway #1:** Taller and narrower erosional niches promote smaller failure masses compared to those with shorter and deeper niches, suggesting that block failure characteristics could be tied to variations in the wave climate that interacts with the coastline.

Impact of vertical tension cracks on displacement, map view



• As fracture depth (F_D) increases, the displacement field transitions from a relatively uniform (along-bluff) pattern to a more concentrated pattern with the maximum displacement located in the section of the bluff face that is seaward of the map-view fracture midpoint.

• **Takeaway #2:** Even relatively shallow vertical cracks can concentrate displacement within ice-bonded permafrost coastal bluffs and may play a role in localizing bluff failure.

• **Conclusion:** Developing a coupled thermo-mechanical model to solve heat transfer and stress for observed atmospheric/oceanographic conditions is critical to (1) explore more complex geometric characteristics of the basal erosional niche and (2) track the development of tension cracks for coastal permafrost bluffs that are prone to toppling mode failure.

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