Seismologists Turned Detectives

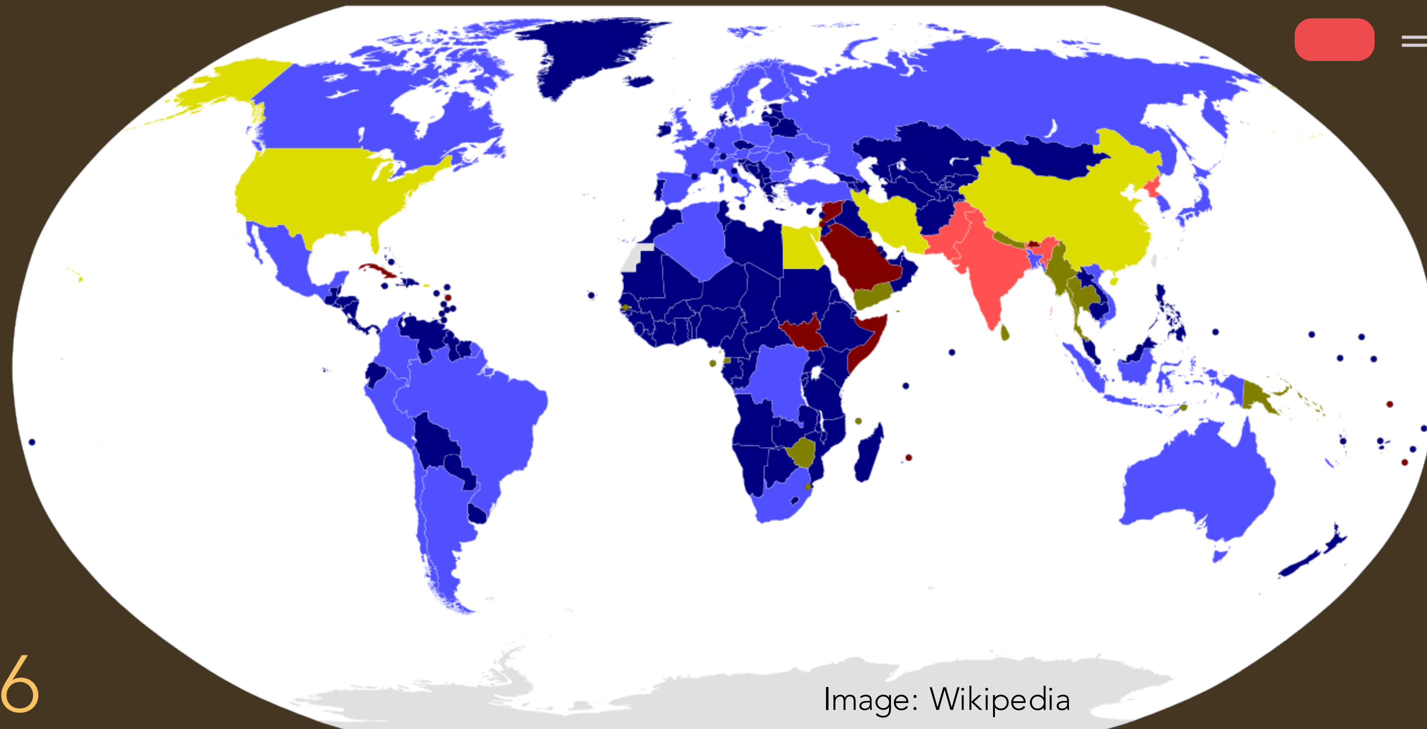
Monitoring Nuclear Test Events Using the Earth's Vibrations

Image: DigitalGlobe

Liam D. Toney

This presentation provides a brief overview of seismic nuclear test monitoring. Specifically, it discusses how data gathered at the Nevada National Security Site is used to build complex models that will eventually help the United States identify nuclear test detonations – carried out anywhere in the world – with greater accuracy and ease. Suggested speaker notes are provided in white text boxes like this one, below every slide.

Context



= Not signed or ratified

- Comprehensive Nuclear-Test-Ban Treaty (CTBT) introduced in 1996
- Pakistan, India, North Korea have not signed or ratified the CTBT
- U.S. and international community want improved capabilities in underground nuclear explosion monitoring

The CTBT was adopted by the UN General Assembly in 1996, in the wake of the Cold War. Nations who ratify it agree to prohibit nuclear explosions of any kind in any environment. There exist very few nations which have neither ratified nor signed the CTBT; of this list, Pakistan, India, and North Korea are of particular note. North Korea conducted its most recent test detonation in January 2016. The U.S. and international community desire improved capabilities in underground nuclear explosion monitoring in order to verify compliance with existing treaties and reduce the potential for nuclear proliferation.

Detection

- Networks of seismometers

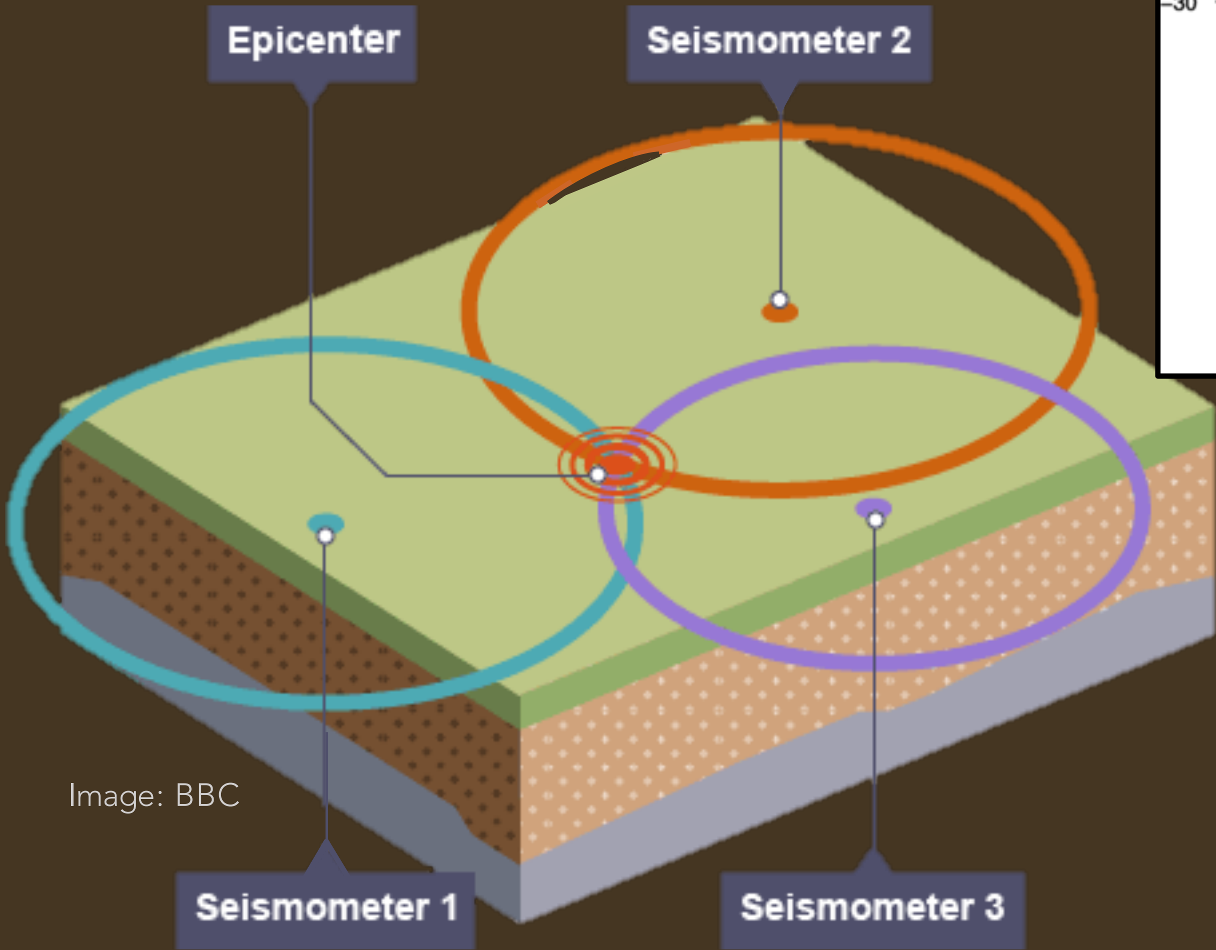


Image: BBC

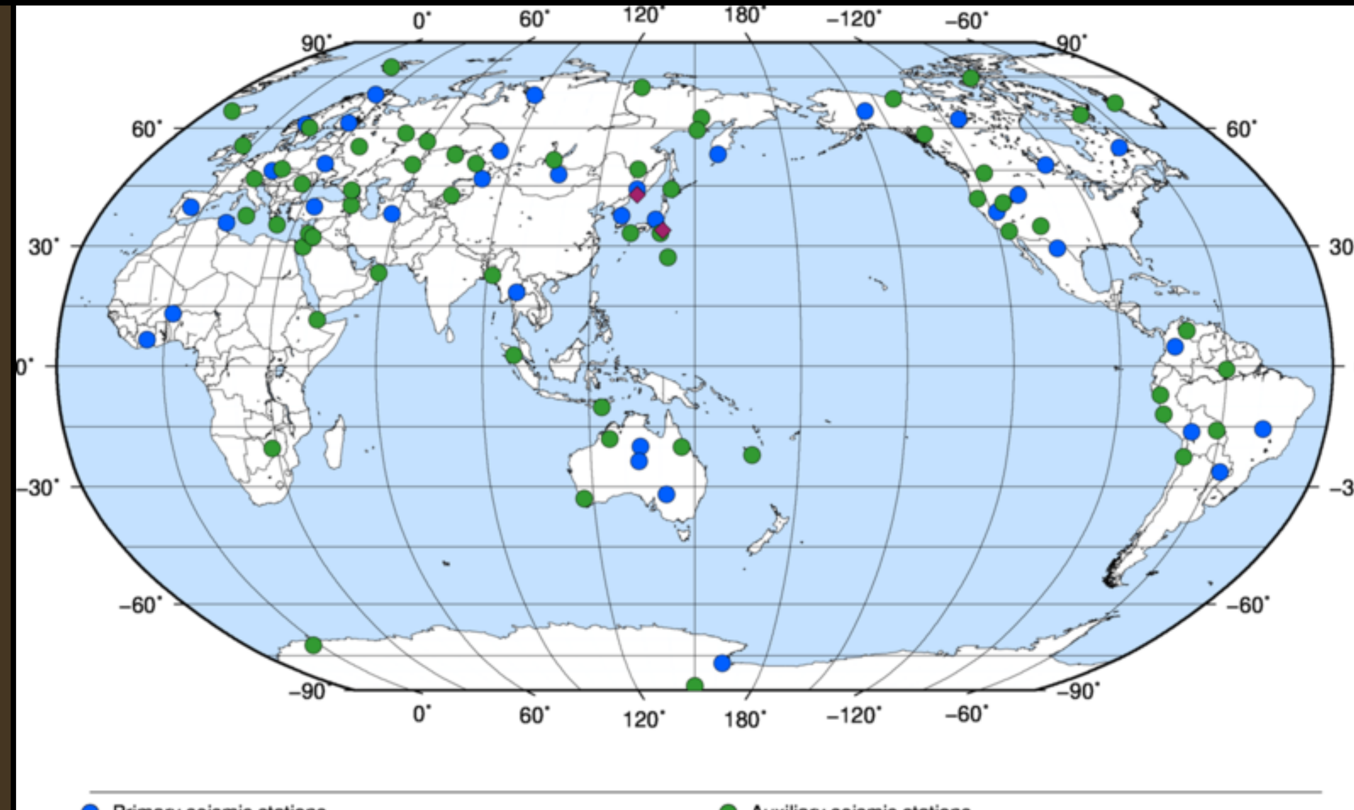


Image: CTBTO

- We can use "triangulation" to locate:
  - Earthquakes
  - Explosions

Vibrations created when the earth shakes in response to an earthquake or explosion travel through the earth and can be registered on seismometers installed anywhere on the surface of the planet. The map on this slide shows which seismic stations recorded North Korea's January test. If enough stations record an event, the event's location can be determined to fairly high accuracy by "triangulation" – see the diagram. Adding more seismometers to the network increases the precision of the location measurement. This method is used to locate both earthquakes and explosions. The question remains: How do we tell the two apart?

Explosions versus Earthquakes

Q: How can we tell the difference?

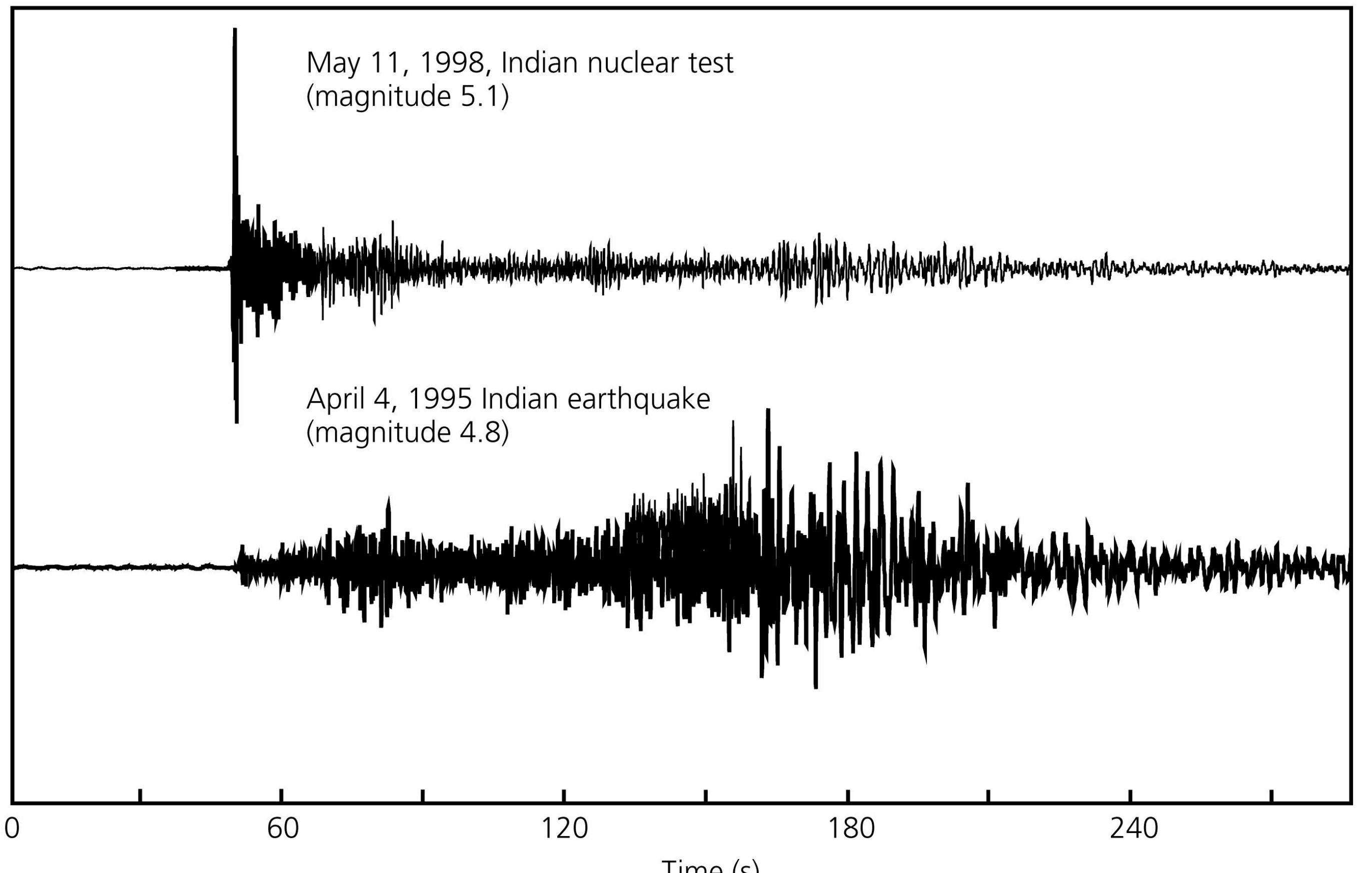


Image: Stein & Wysession

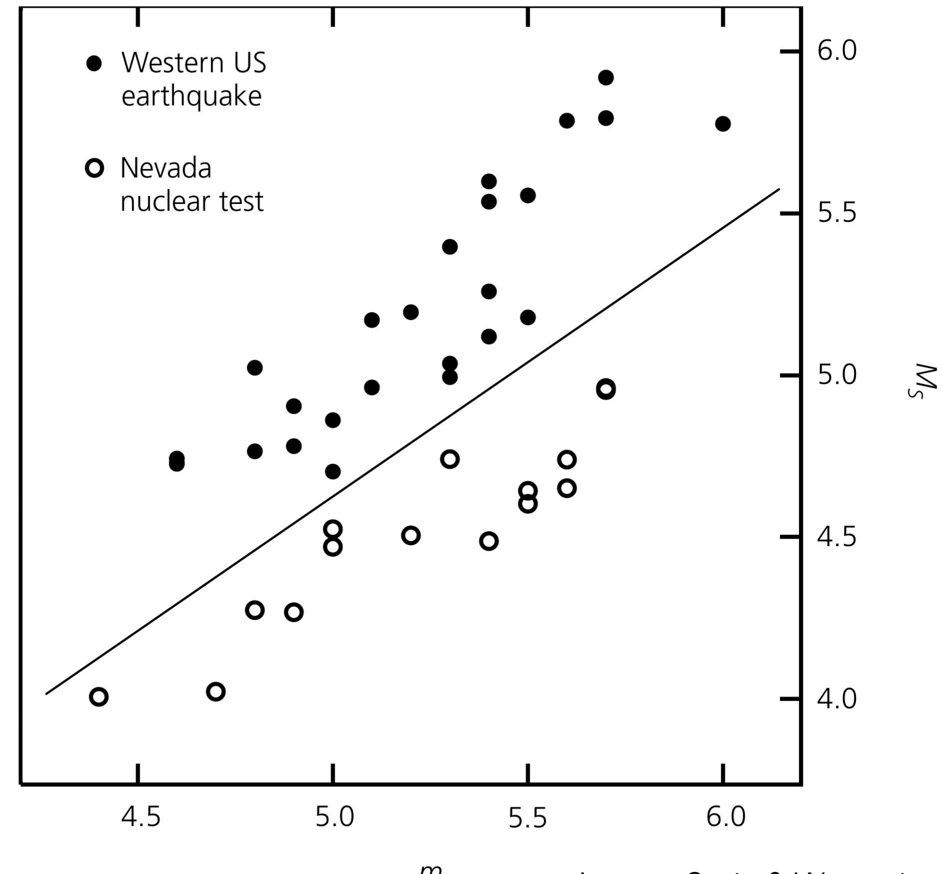


Image: Stein & Wysession

A: They produce different vibration patterns!

Explosions and earthquakes usually have very different seismic "signatures." In an earthquake, ground motion is caused when two tectonic plates slip; this process occurs quickly, but it still takes a non-negligible time period for the ground to move. That's why the vibrations of an earthquake arrive gradually (bottom wiggle). An explosion occurs in a fraction of a second, which causes the record of vibration to look more like the top wiggle. Also, we can see from the plot on the right that the ratio of energies for seismic waves travelling through the earth (m_b) versus those travelling on the surface (M_S) is different for earthquakes versus explosions.

Problems…

- North Korea's recent nuclear test detonations fall on "wrong" side of line

Image: BBC

- Better model is needed!

Empirical

Physics-based

An unrealistic model…

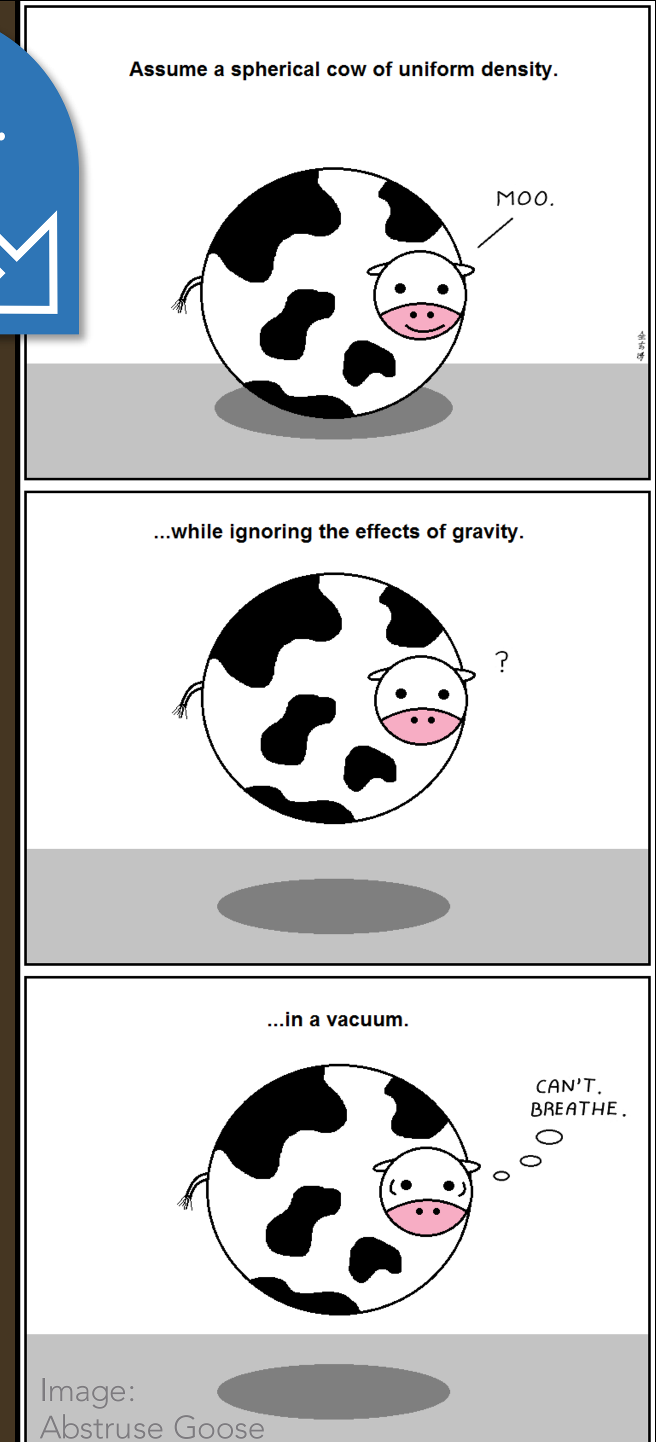


Image: Abstruse Goose

The previous slide makes it seem like differentiating between explosions and earthquakes should be fairly easy, since their seismic characteristics are so different. A "model" can be created – a simplified representation of reality that allows scientists to swiftly categorize seismic events. However, this empirical (observation-driven) model doesn't work well with the data from the smaller North Korean detonations. Instead of relying upon past observations to define a model, scientists seek to create a new model that takes into account the physical properties of the explosion, such as the bomb's size (and depth of burial) and the regional geology.

The Source Physics Experiments

- Chemical explosions with varying parameters:
  - Bomb size
  - Depth of bomb burial
  - Regional geology
- Take place at NNSS (formerly Nevada Test Site)

GOAL: Take lots of data, understand the *physics!*

Image: Rich Rose, LANL

The Source Physics Experiments are one major project working towards the realization of a better, physics-based model. They consist of a series of chemical explosions at the NNSS (Nevada National Security Site). The explosions are of varying size and burial depth, and they are buried in areas of varying geology (granite, looser material, etc.) as well. The seismic wave data created during these explosions (as well as other data) are used to build models that – eventually, if all goes well – will be capable of predicting the ground response for a given explosion. These will help the U.S. better discriminate between nuclear explosions and earthquakes.

Project THOR

- Models are more accurate if local geology is accounted for
- "Active-source" data collected:
  - Seismic Hammer™
  - Modified industrial pile driver
  - Hammered surface at NNSS
  - Weighs 14 tons ⟷ five SUVs

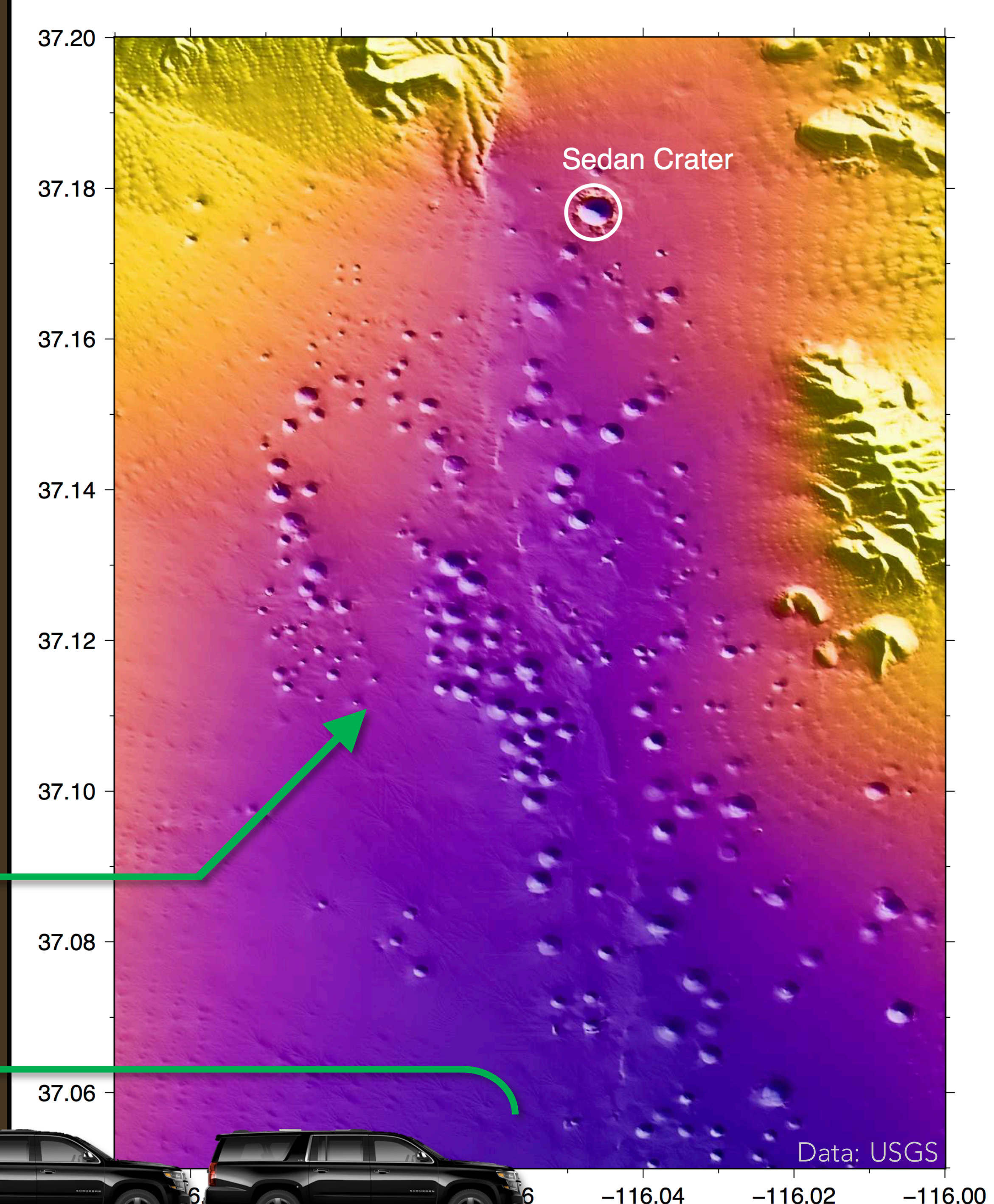


Image: Chevrolet

In order to better inform the models, it's helpful to have a baseline understanding of the geology where the next explosions are to be conducted. Project THOR seeks to "image" Yucca Flat, an area of the NNSS where the next phase of explosions will take place. Using a massive pile driver called the Seismic Hammer™, scientists hammered the surface of Yucca Flat repeatedly down lines stretching in both the north-south and west-east directions. Large numbers of geophones (small seismometers) were placed along these two lines to capture the vibrations created by the hammer. The data from THOR is currently being processed.

Tomography 101

It's like an X-Ray for the earth!

tomography –

a technique for imaging the structure of an object using a penetrating wave

- Seismic waves move through different rock types at different speeds
- We can build a "velocity model" of what's underground

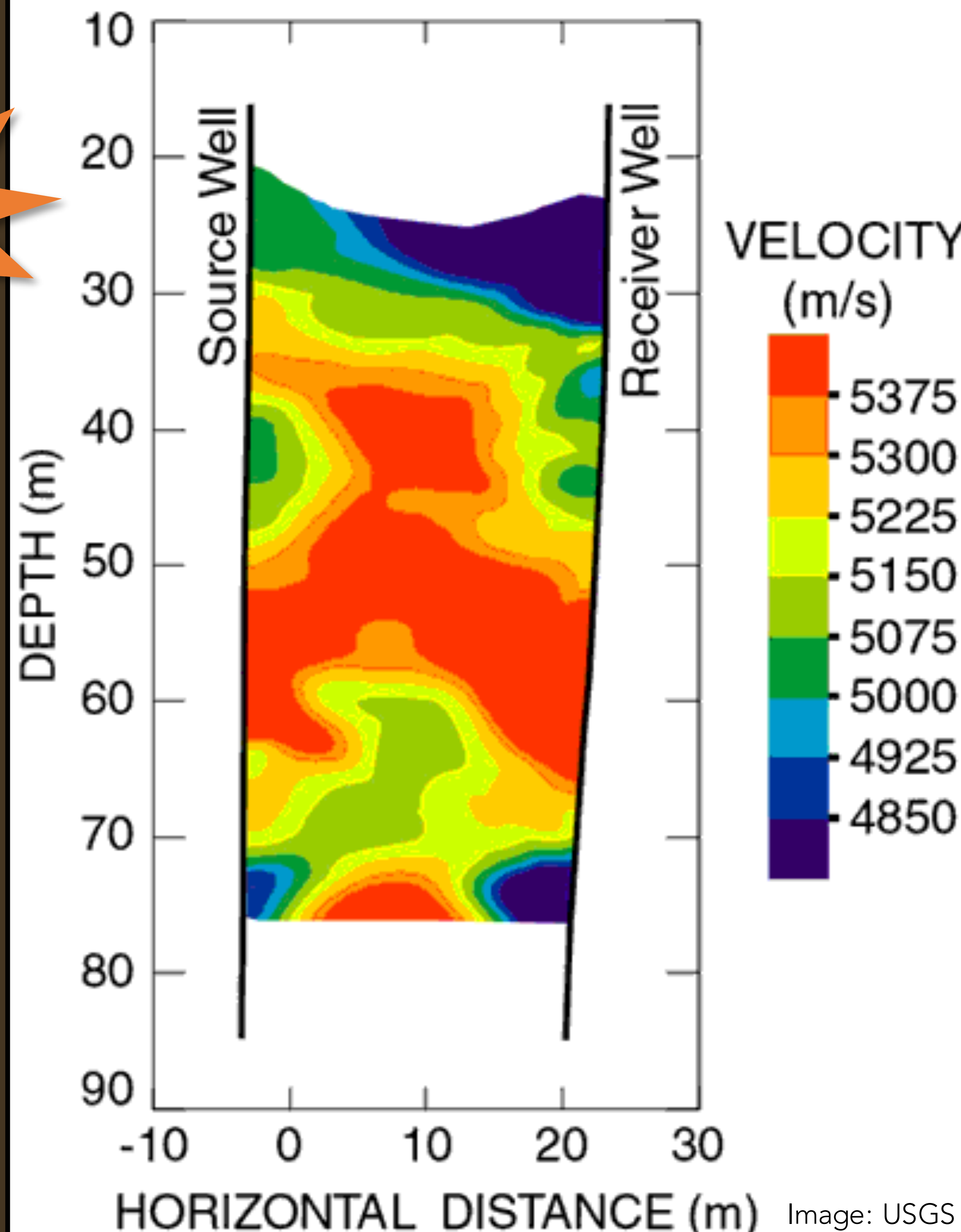


Image: USGS

Seismologists can use seismic data to perform *tomography*. Tomography leverages the fact that seismic waves travel through the earth and reflect off of – or pass through – underground boundaries. Layers of differing rock type exist within the earth, and seismic waves travel at different speeds through these different layers. If we have enough "shots" (hammer hits, in this case) and enough seismometers (geophones, in this case) we can build a model like the one shown in the plot above. Since we usually know the rough correspondence between rock type and velocity, we can therefore make an educated guess about the earth's composition.

Insights from THOR

- Tomography is being performed on THOR data

Image: Wikipedia

- Seismic waves are highly scattered near sites of previous U.S. nuclear tests

The technique of tomography is being performed on THOR data; the goal is a velocity model of what's underneath Yucca Flat. This will then be used to understand the structure and makeup of the area's underlying rock. Already, preliminary results indicate that the existence of large craters (and their underlying broken rocks) significantly alters the paths of seismic waves travelling from the site of the hammer blow. The seismic waves "scatter" when they interact with a previous detonation area, similar to the behavior of light rays when they strike a multi-faceted prism, like a diamond. This interesting discovery will be useful for the modeling team.

Moving Forward

- Integrate THOR data into explosion models
- Continue experiments while varying physical conditions

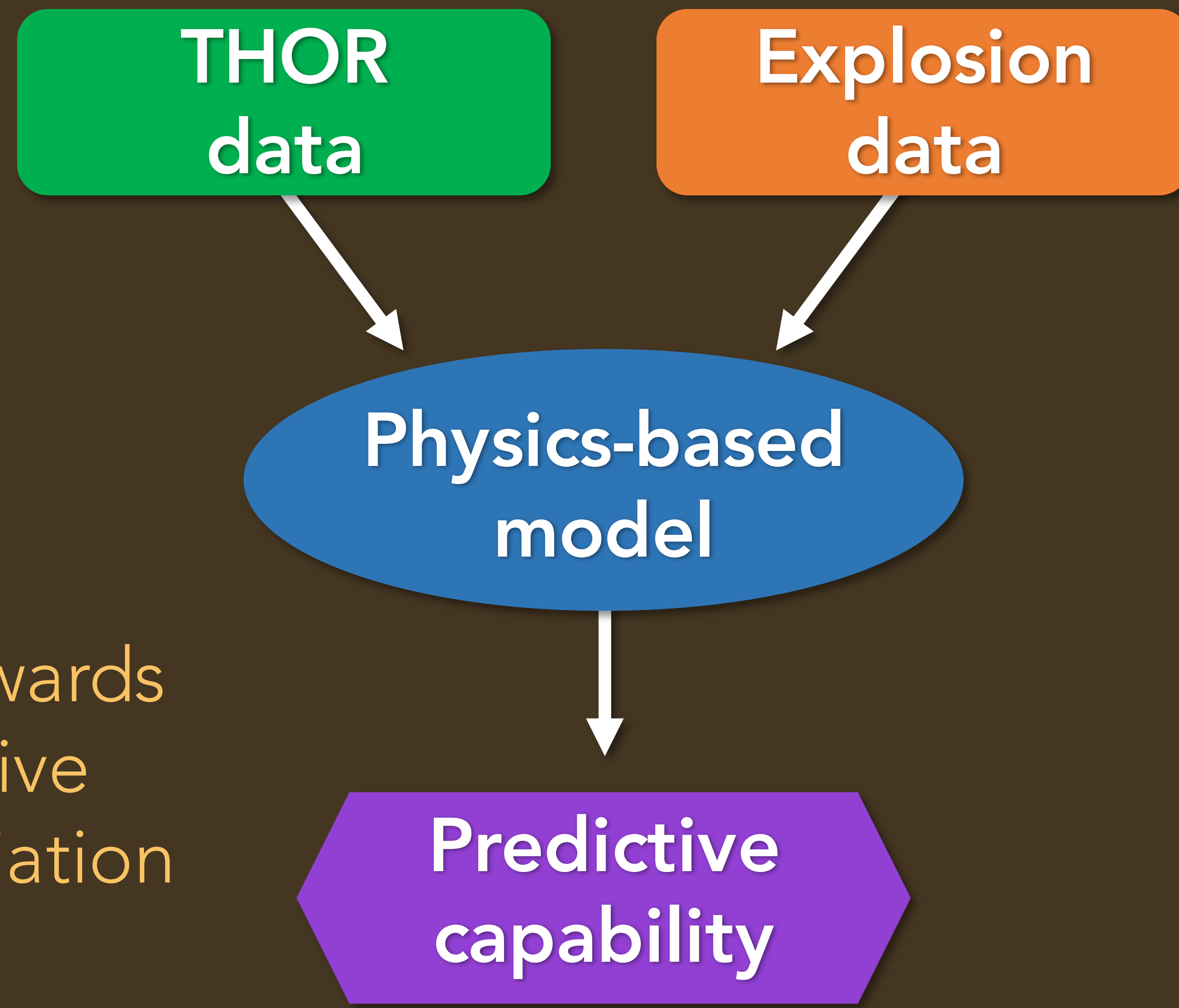


Image: Wikipedia

- Work towards an effective differentiation method

Once the THOR data has been fully processed and satisfactory tomographical models have been obtained, the next step is to apply the results of THOR towards the explosion modeling effort. This may include altering baseline parameters, refining model response, or any number of other additions and modifications. If the project is a success, the U.S. will have physics-based models that will enable better discrimination between earthquakes and underground nuclear explosions.