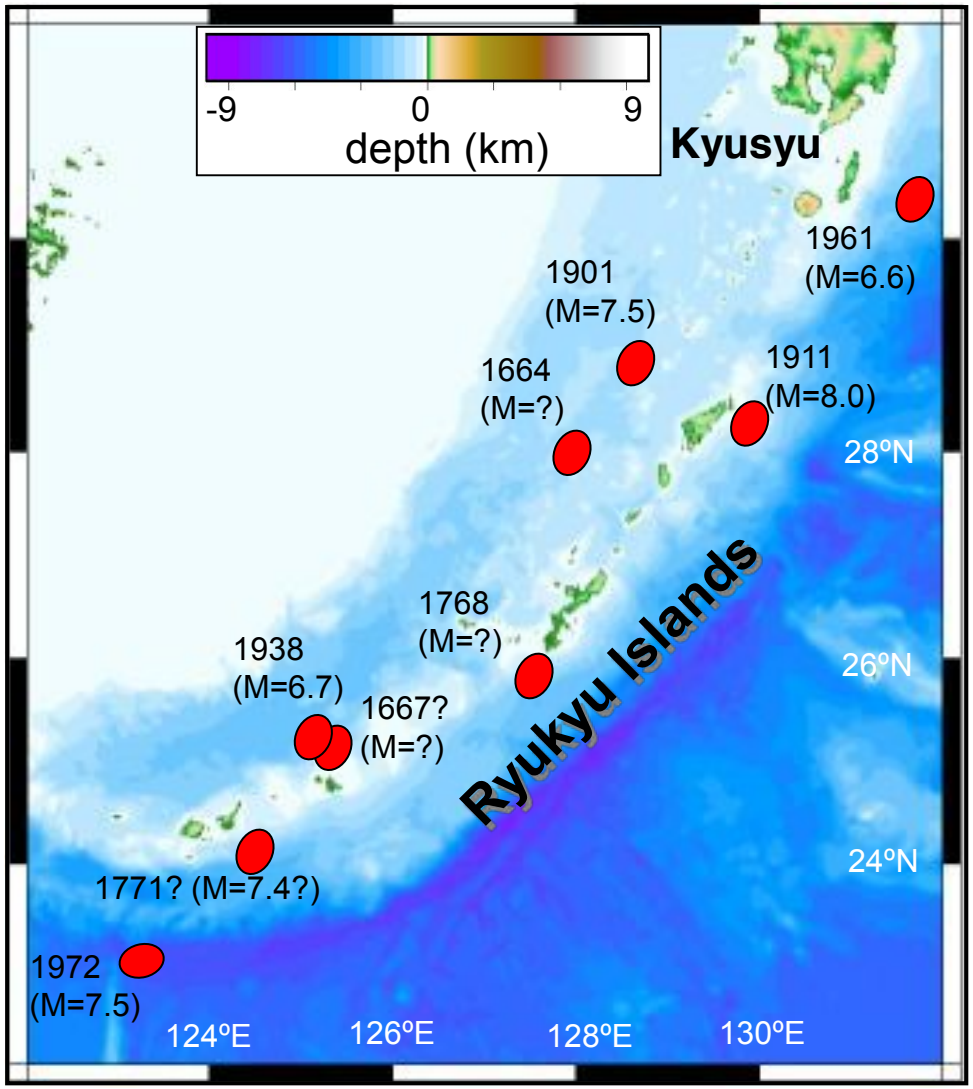
The paleotsunami histories along the Ryukyu Islands inferred from coastal boulders

Kazuhisa Goto (Tohoku University)

400 years historical records of the earthquake and tsunami along the Ryukyu Trench



Minor tsunami (few meter in run-up height): 1960 Chilean tsunami, 1911 Kikaijima tsunami, 1625 Sakishima tsunami.

Large tsunami (~30 m in run-up height): 1771 Meiwa tsunami.

Goto et al. (2010) Earth-Science Reviews

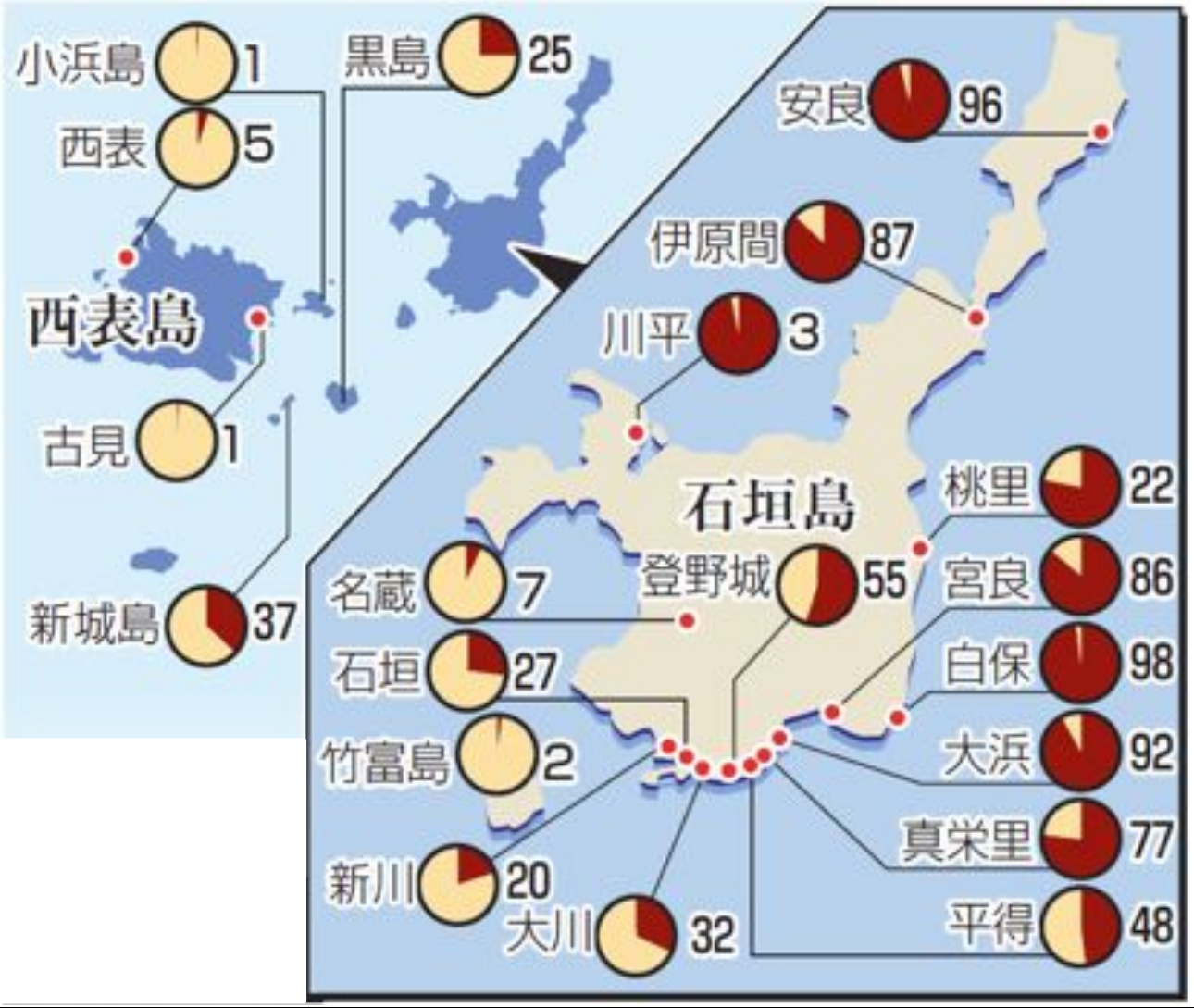
No information before 400 years ago

The 1771 tsunami affected to the southern Ryukyu Islands

Totally 12,000 peoples were killed by this tsunami at Sakishima Islands.

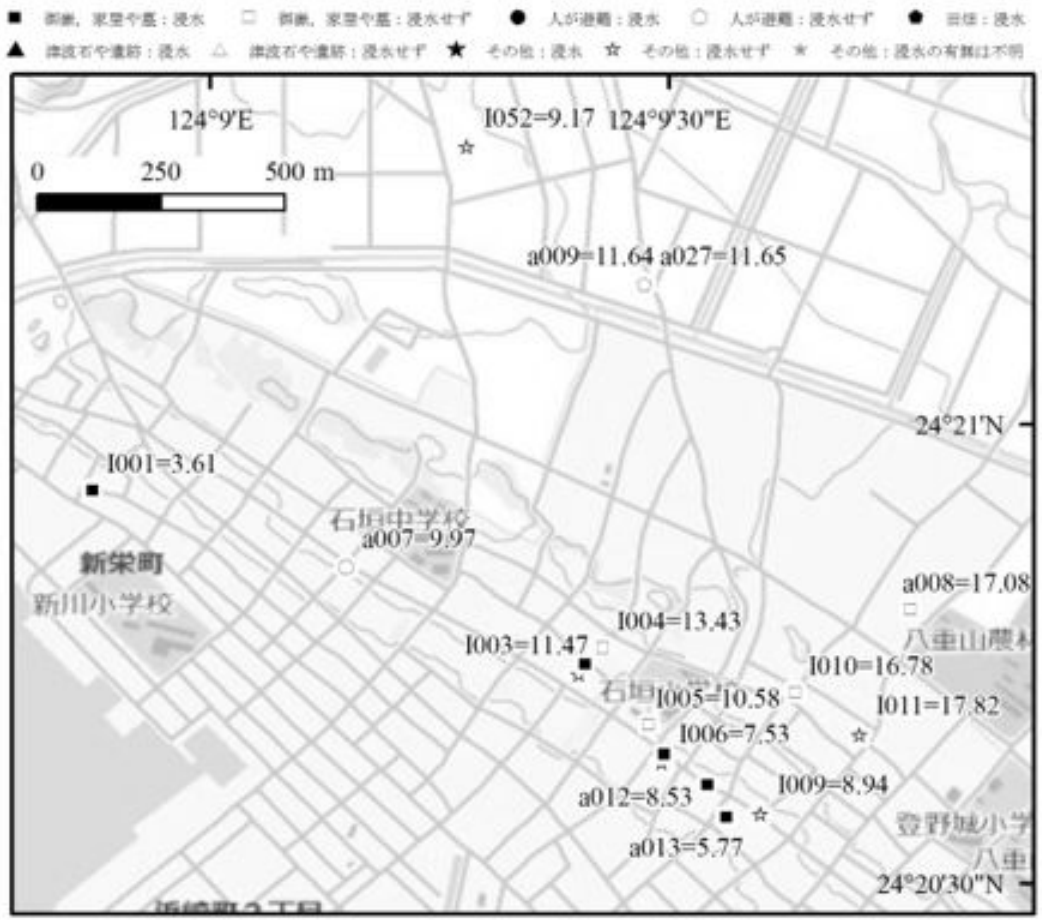
Not affected to the Yonaguni Island and Taiwan.

Fatality ratio (%) at Yaeyama Islands



Copyright: Kyodo Tsushin

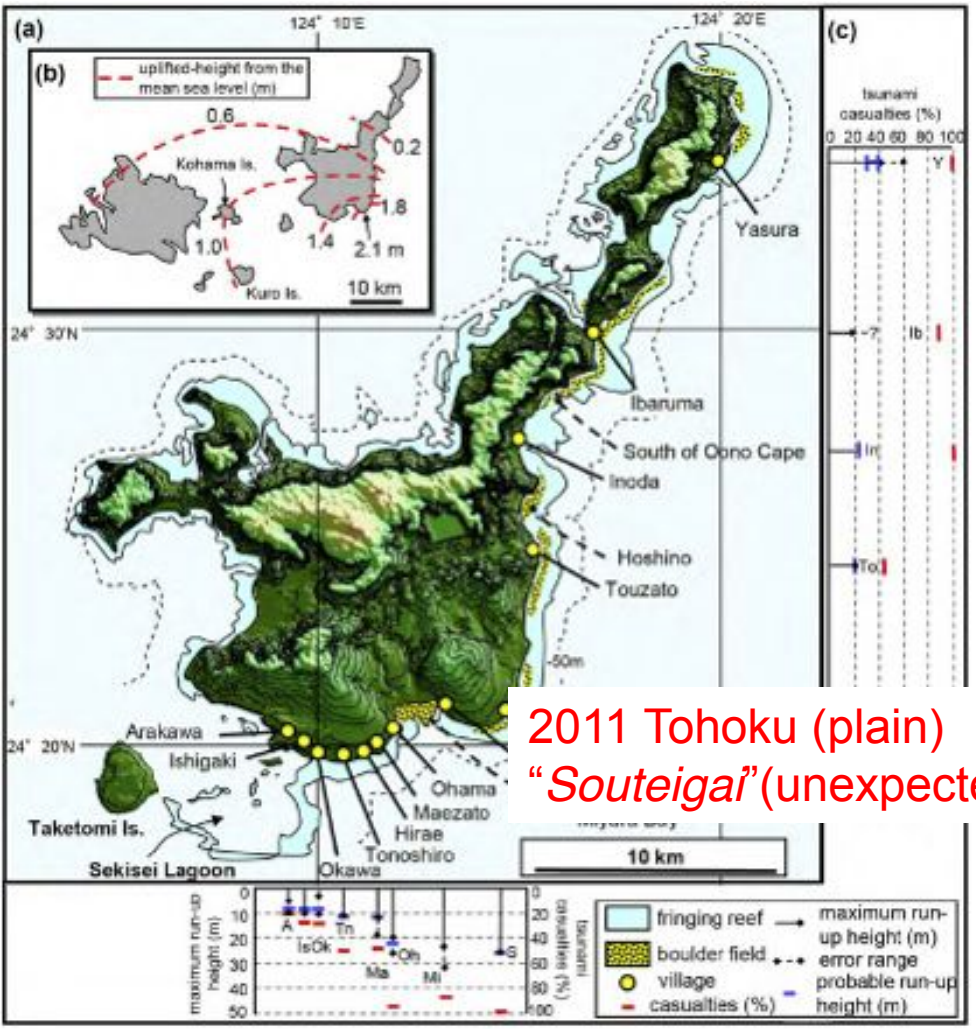
Measurement of the flow depth/run-up height of the 1771 event based on the historical documents



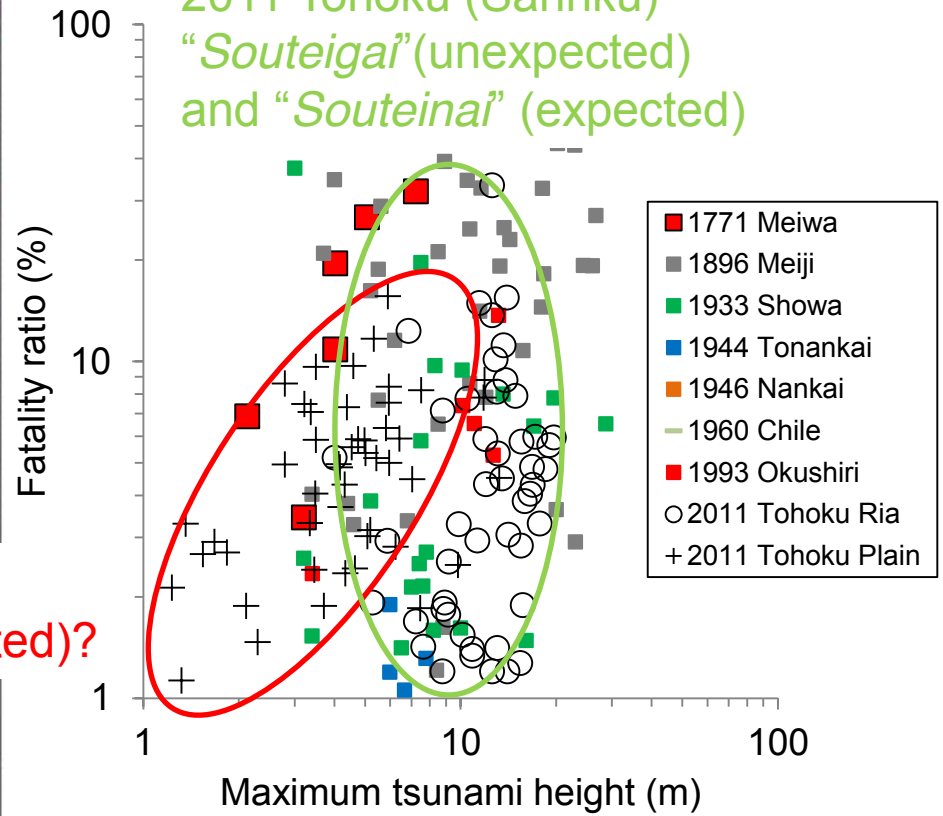
Totally ~100 sites were measured and the inundation area and run-up heights were estimated.

Goto et al. (2012) Tsunami Engineering (in Japanese)

Run-up heights and fatality ratio



2011 Tohoku (plain)
"*Souteigai*"(unexpected)?

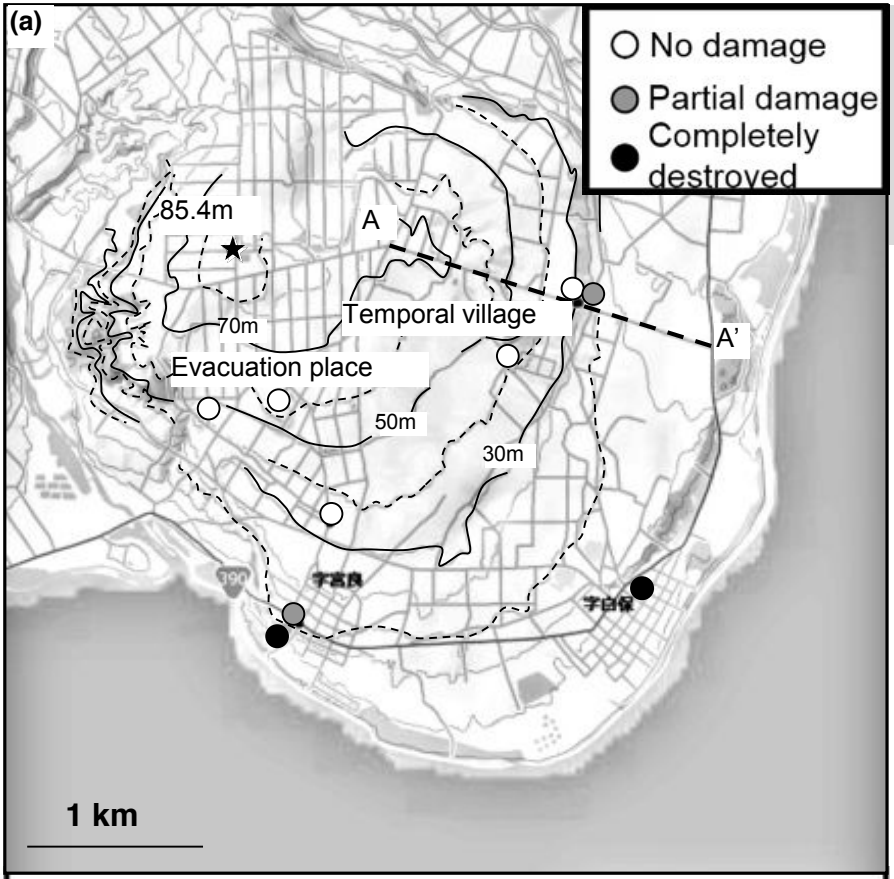


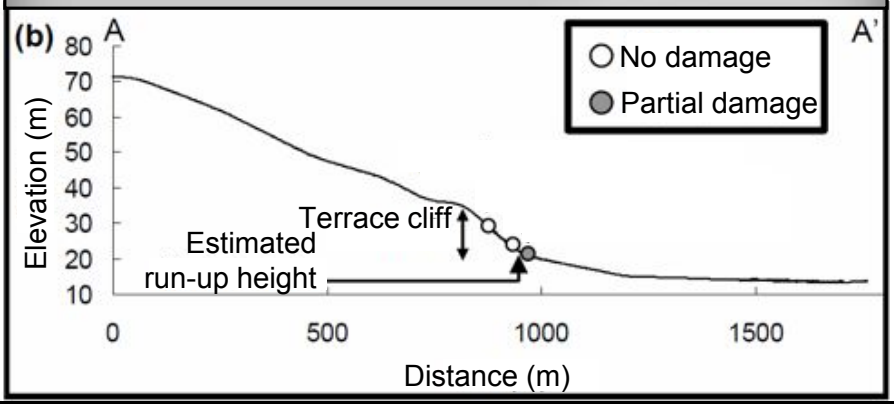
Courtesy: Anawat Suppasri

The 1771 event was the **OLDEST** and **WORST** example in terms of the fatality ratio in Japan regarding to the historical events. Probably it was an unexpected (***Souteigai***) event without known previous event.

Goto et al. (2010) Earth-Science Reviews, Goto et al. (to be submitted)

Was the maximum run-up 85 m? NO!

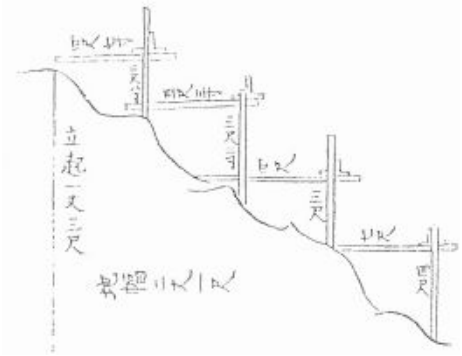




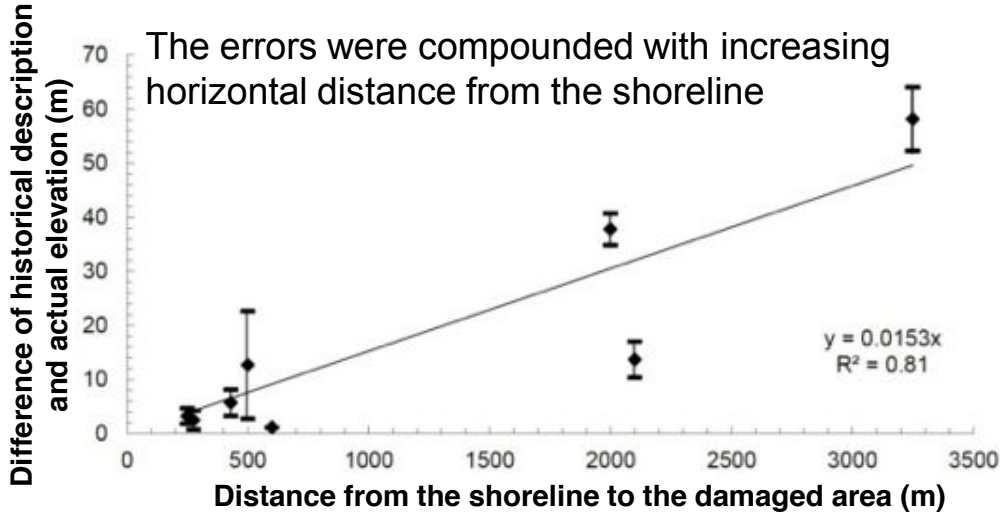
It is described that 85.4 m is the maximum run-up height at the southeast of Ishigaki Island. However, there are another description that said no damage at lower elevations

How did local people measured run-up heights after the tsunami?

They used door of house to measure the horizontal level. Vertical error of 11 cm for 3 m in horizontal difference.



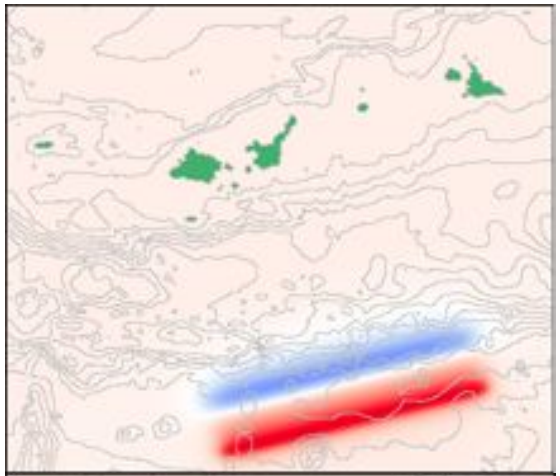
The errors were compounded with increasing horizontal distance from the shoreline



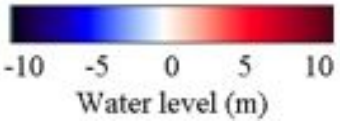
Goto et al. (2012) Tsunami Engineering (in Japanese)

Where was the source of the 1771 tsunami?

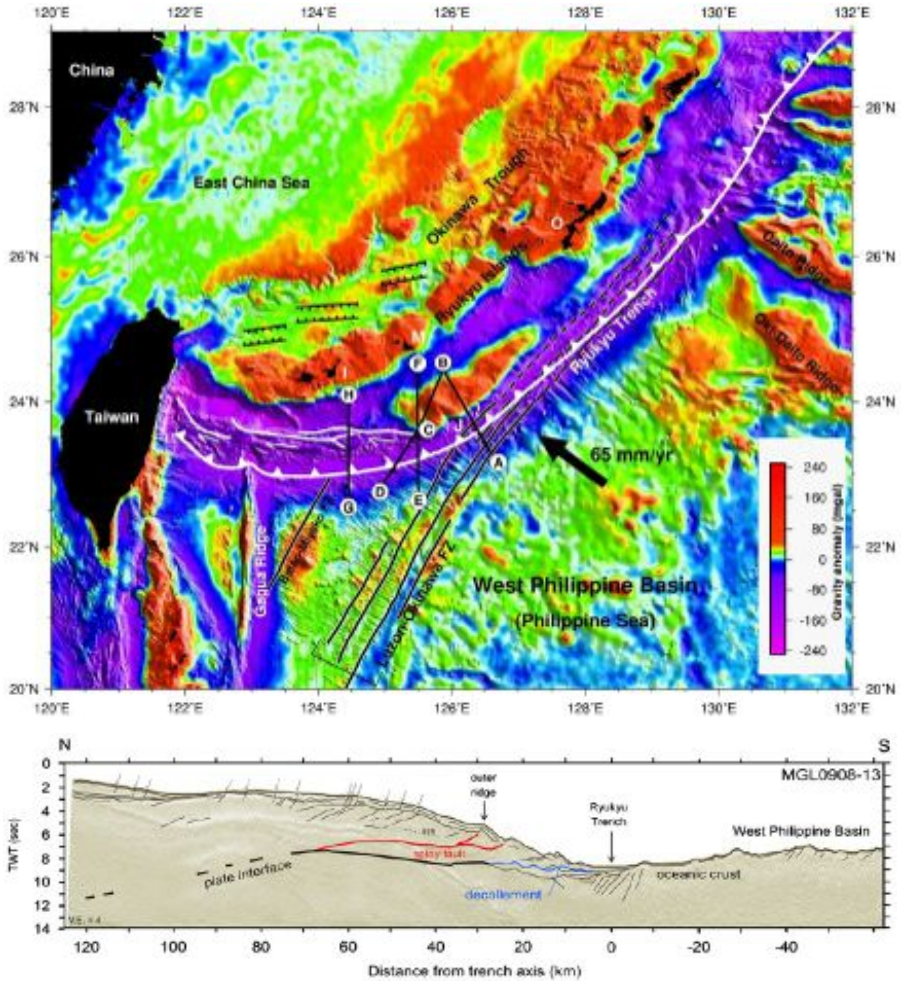
Tsunami earthquake?
(Mw=8.0, 16 m in slip amount)
Nakamura (2009)



Earthquake and landslide?
(Mw=8.1＋L)
Miyazawa et al. (2012)



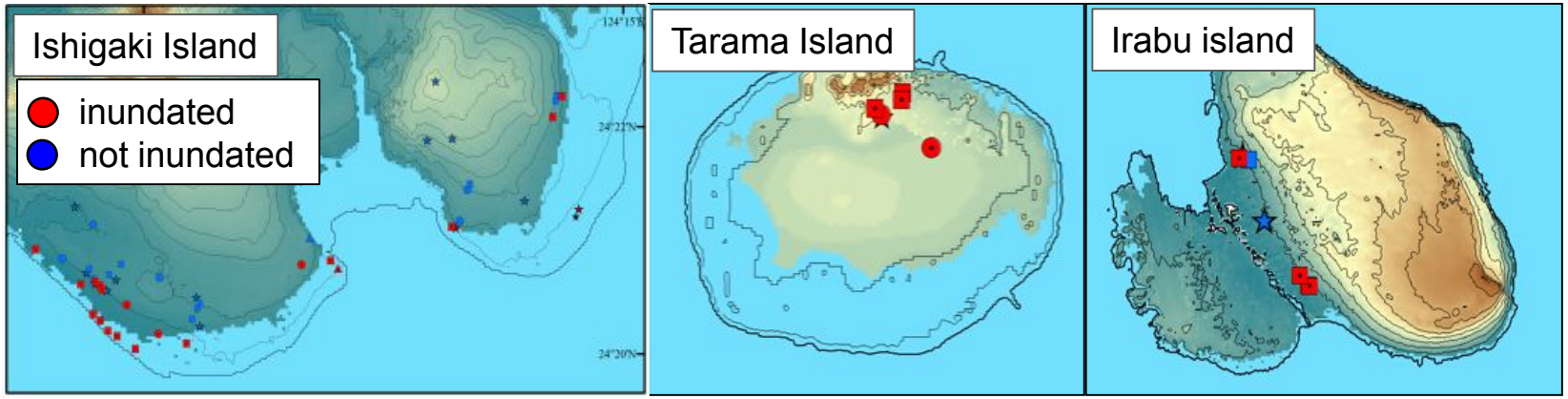
Spray fault?
Hsu et al. (2013)



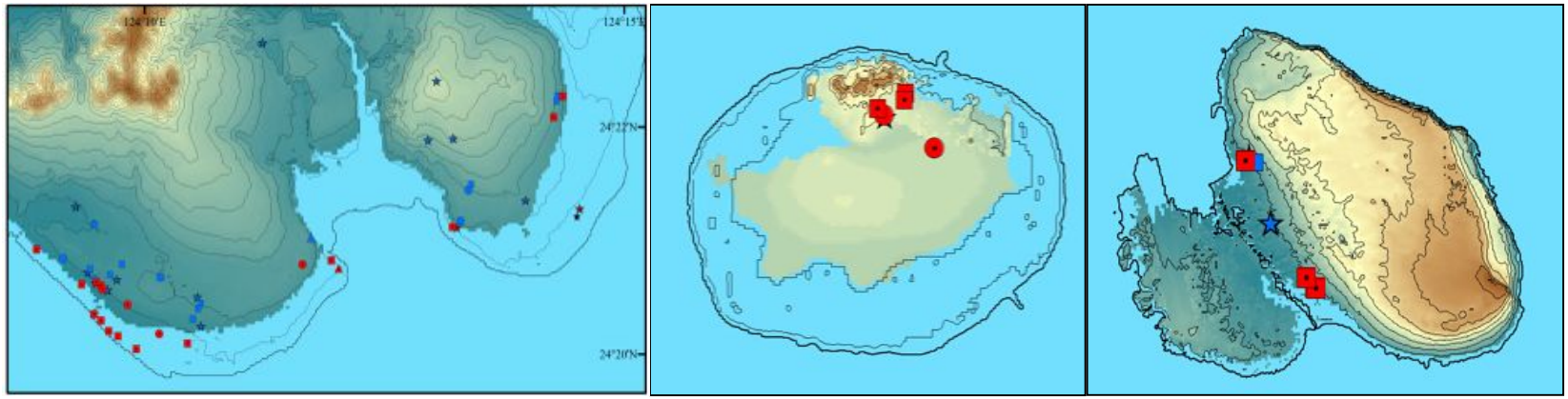
Nakamura (2009) GRL, Miyazawa et al. (2012) Advances in Natural and Technological Hazards Research, Hsu et al. (2013) EPSL

Comparison of the inundation by each model

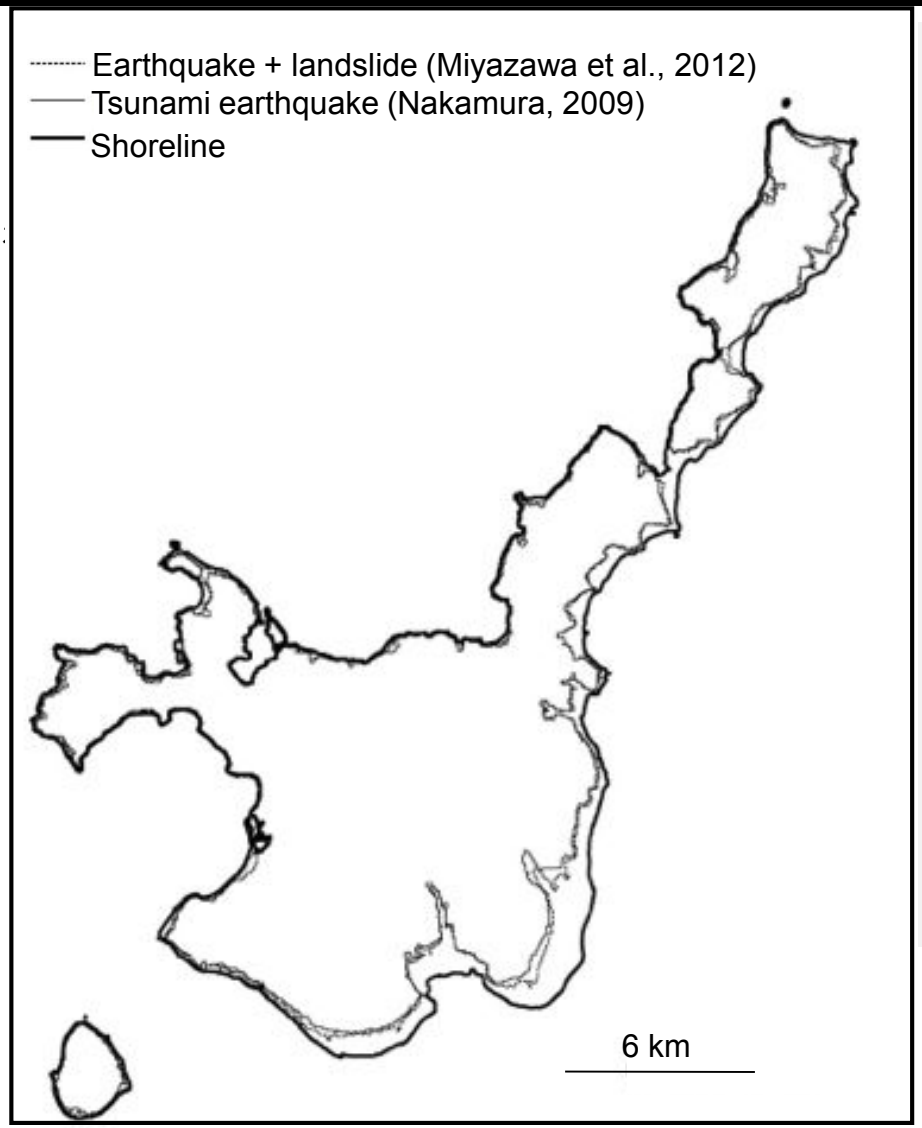
Tsunami earthquake?
（Mw=8.0, 16 m in slip amount）
Nakamura (2009)



Earthquake and landslide?
（Mw=8.1＋L）
Miyazawa et al. (2012)



Can scientist really specify the fault model?

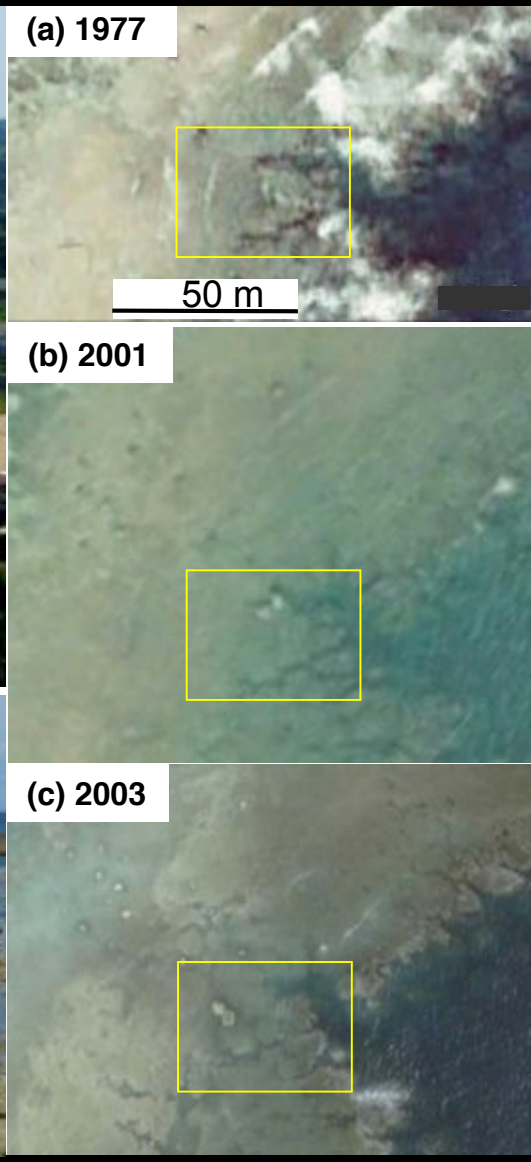


- **It is (always) difficult to specify the fault model**. Local government confuses which model should they use for risk assessment.
- **There is no difference of inundation area and run-up height in each model** simply because all models were tuned to fit the historical descriptions.
- We have recommended the local government not to exclude any models and consider the worst scenario for the disaster prevention purpose.

Science discussion is important but we should go forward for preparation of the local disaster prevention plan.

Paleotsunamis before AD1771

Boulders on the reef at the Ryukyu Islands

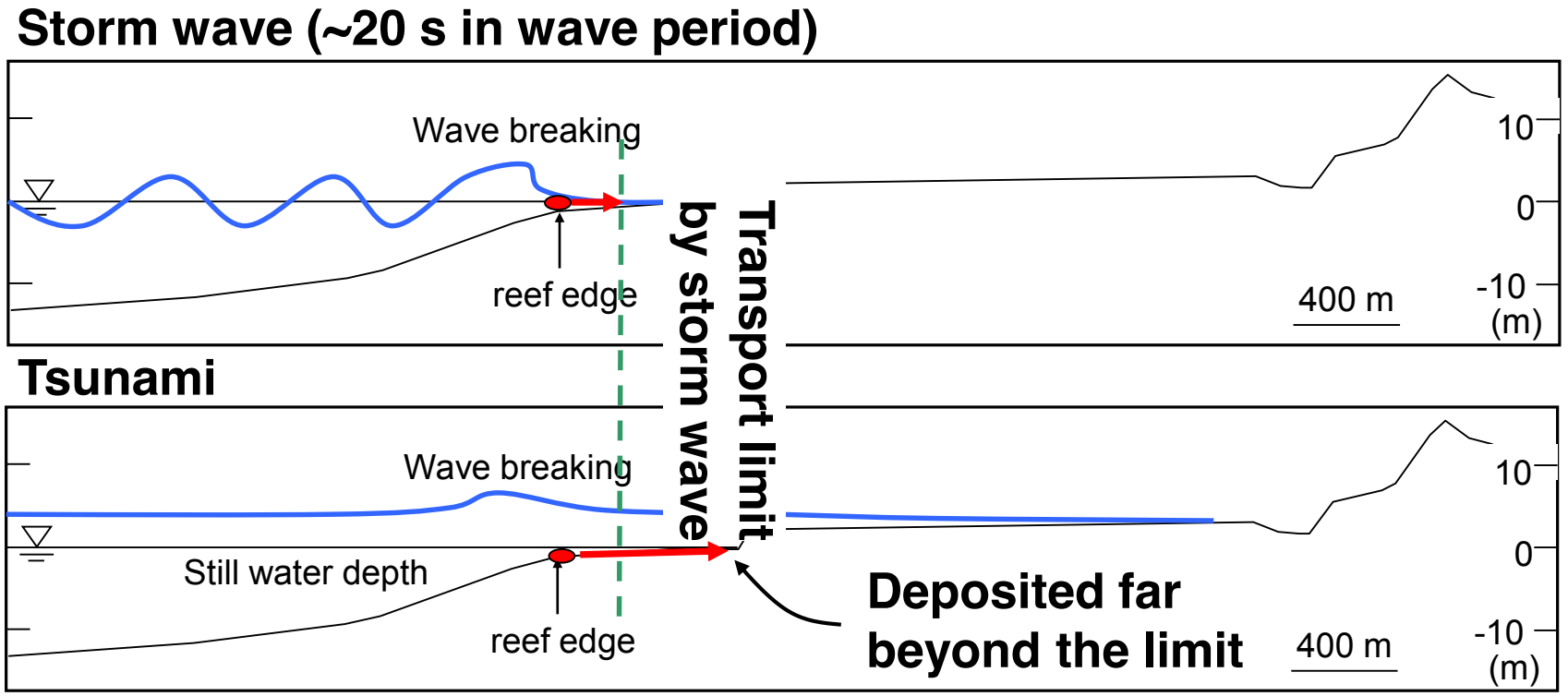


Boulders were deposited not only by the tsunamis but also by storm waves.

Goto et al (to be accepted)

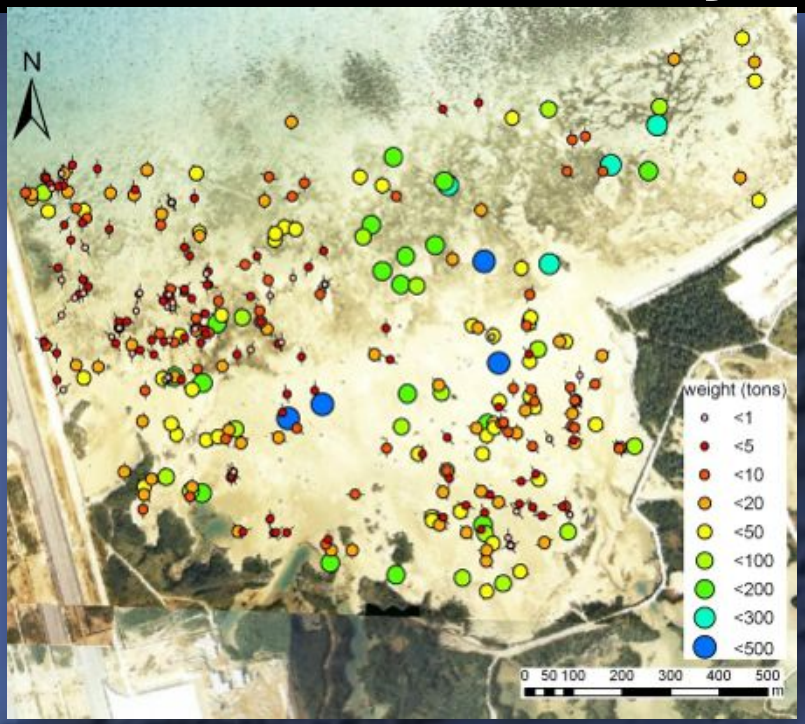
How shall we discriminate?

Significant difference between tsunami and storm wave is wave period rather than height. Thus, transport distance of boulders should be different between tsunami and storm wave boulders.



Imamura et al. (2008) JGR-Oceans, Goto et al. (2009) Marine Geology

Field survey at the Ryukyu Islands



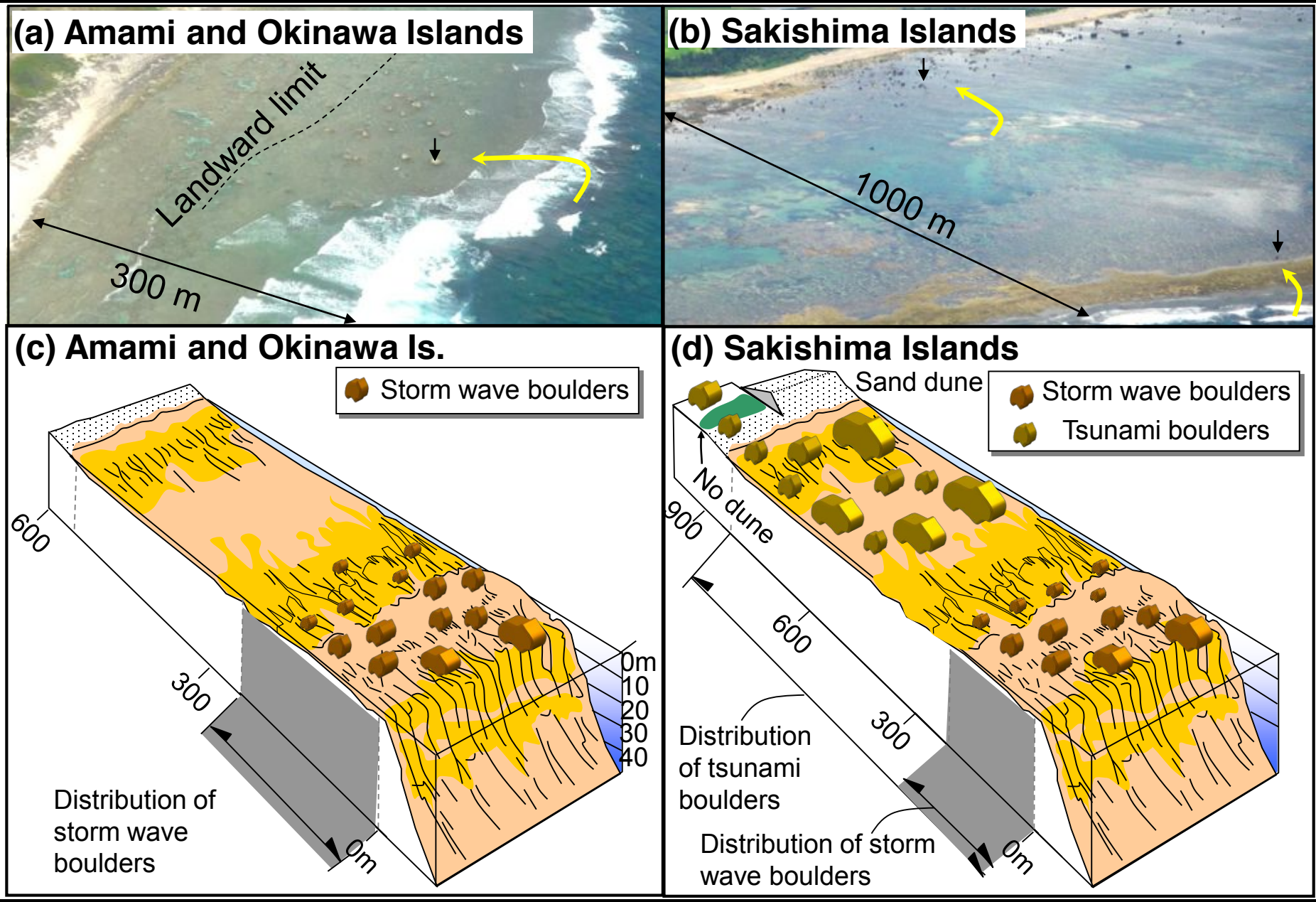
Amami Islands

Okinawa Islands

<u>Sakishima Islands:
affected by the 1771 Meiwa tsunami</u>

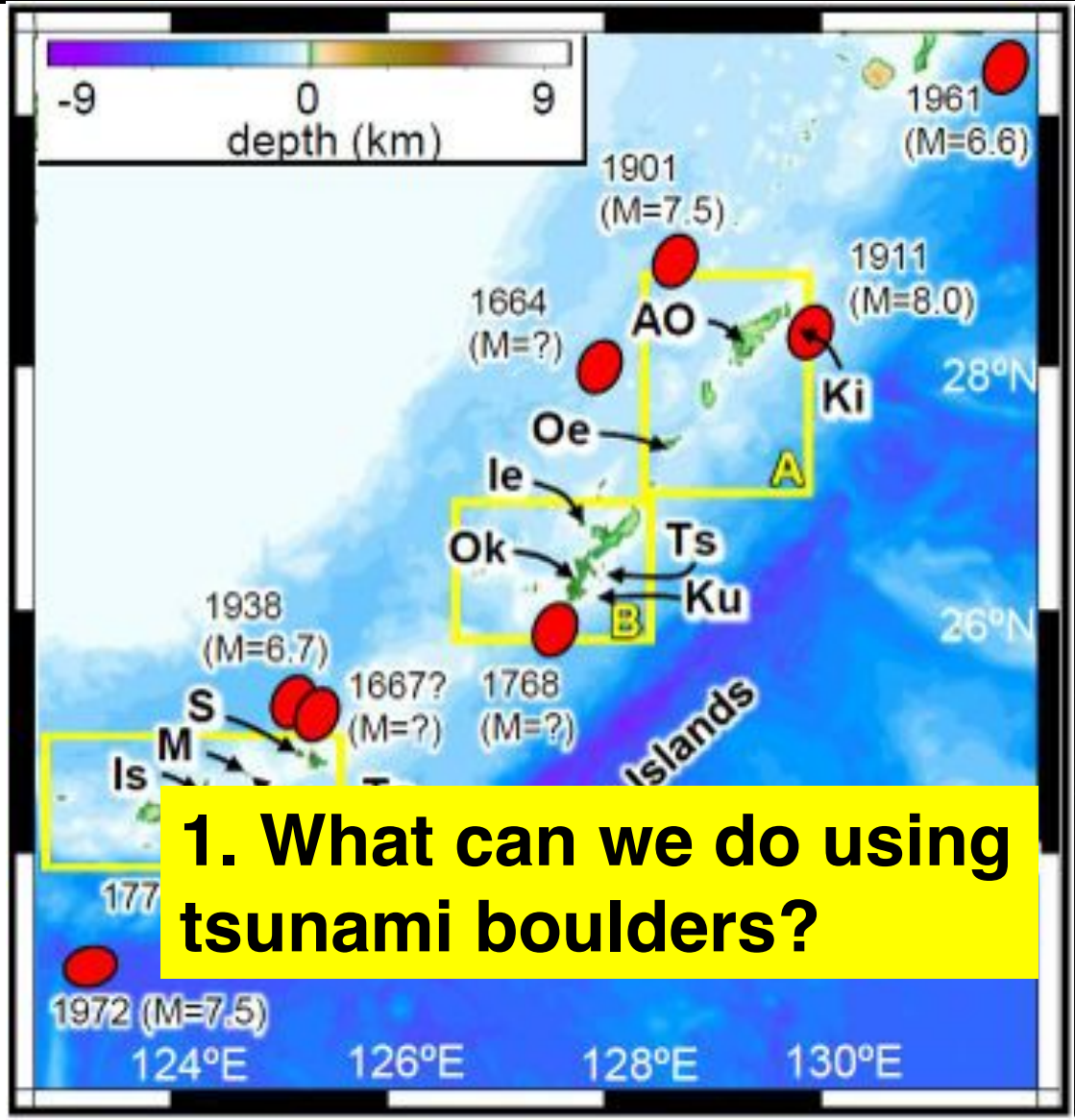
22 survey area at 15 islands after 2007. Total boulders studied were about 5000!

Discrimination of tsunami and storm wave boulders

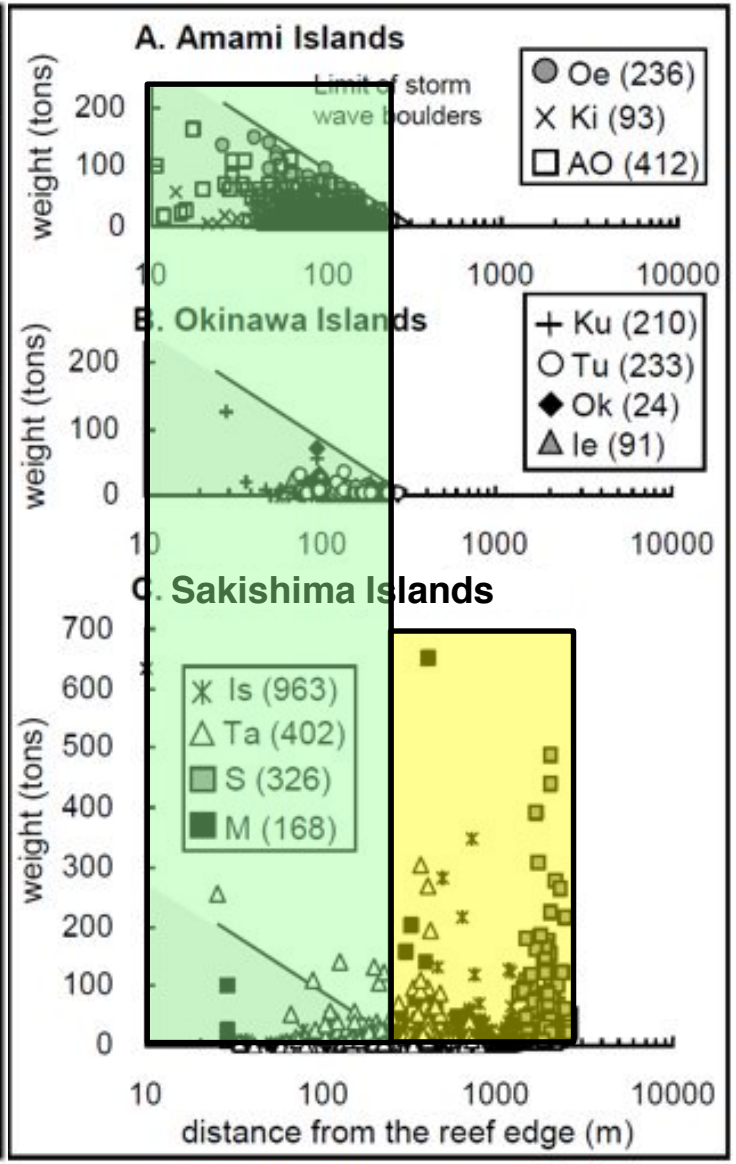


Goto et al. (2010a,b) Marine Geology, Earth-Science Reviews

Distribution of tsunami and storm wave boulders



1. What can we do using tsunami boulders?



1. Storm wave boulders are observable at all Islands groups. ***Goto et al (to be accepted)***

2. Tsunami boulders exist ONLY at Sakishima Islands.

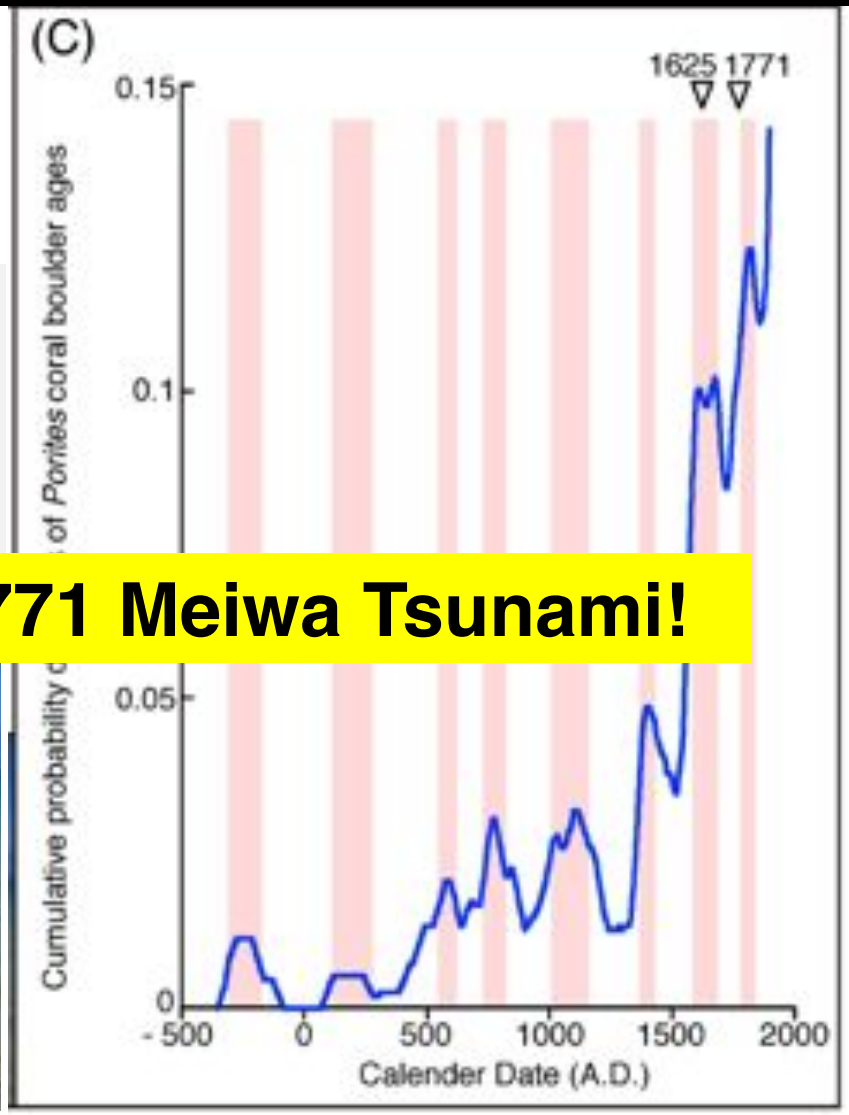
What can we do using tsunami boulders?

The paleo-tsunami histories estimated from the *Porites* tsunami boulders at Sakishima Islands

We used radiocarbon techniques to date **92 *Porites* coral tsunami boulders** collected from the Sakishima Islands.

Tsunami recurrence is estimated as about **150-400 years**. However, all events were not necessarily the 1771-size event.

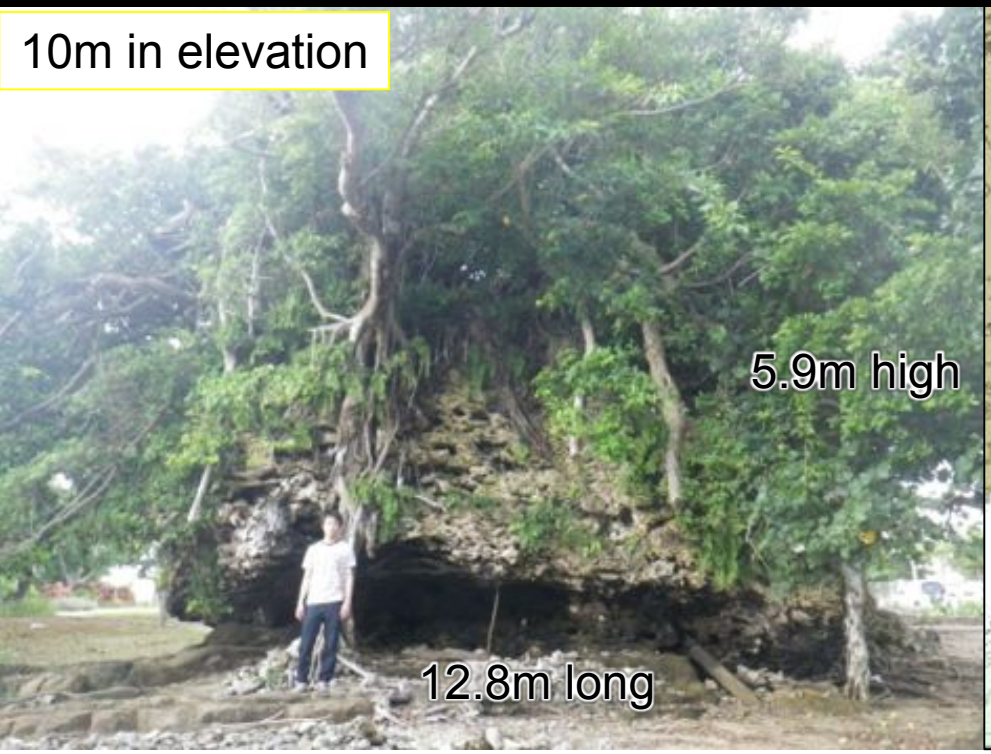
242 years since the 1771 Meiwa Tsunami!

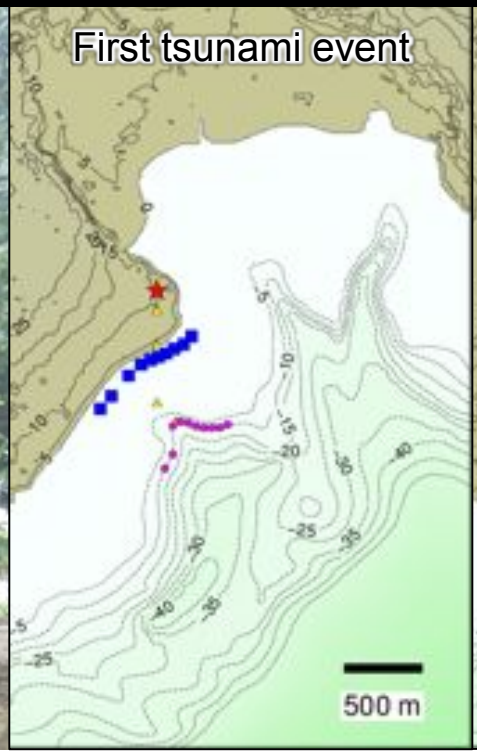


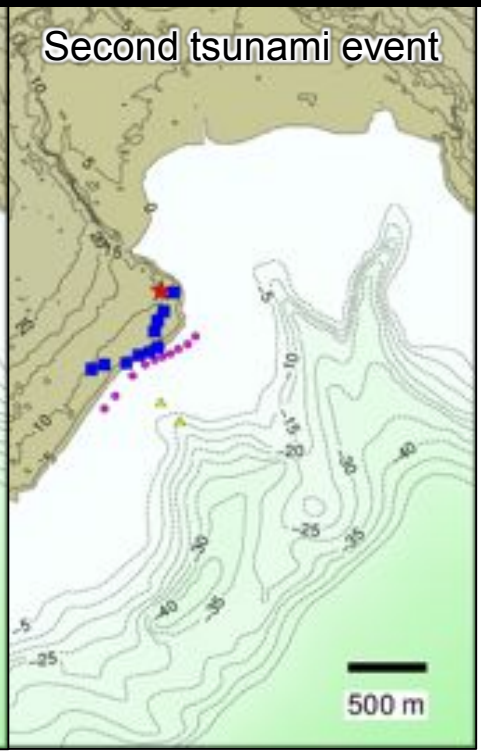
Araoka et al. (2013) Geology

What can we do using tsunami boulders?

Numerical modeling for boulder transport







1. The boulder (*Tsunami-ufu ishi*) was cast ashore at about 2000 BP according to 14C dating of coral (Kawana and Nakata, 1994).
2. Archeological evidence suggests possible collapse of local advance culture.
3. Paleomagnetic analysis revealed TWO rotation histories (Sato et al., 2013).
4. Historical document indicate this boulder was probably not moved by the 1771 event.

Numerical modeling revealed that (1) **SINGLE extremely large tsunami** (few times larger in run-up height than the 1771 event) or (2) **TWO 1771-size tsunamis** are required to cast ashore this boulder at its present location. THREE 1771-size tsunami during past 2000 years? Cyclic events (probably NO)?

Tsunami boulders at Ishigaki Island were designated as national monument in Japan

津波石群、国の天然記念物に

全国初 津波大石（大浜）など4カ所

国の天然記念物に指定された大浜の津波大石 ＝15日午後

石垣島東海岸の津波石群

	最大直径	奥行き	高さ
安良大かね	約7.5m	約3.9m	約2.4m
あまたりや潮荒	約7.3m	約6.1m	約2.6m
高こるせ石	約7.6m	約5.0m	約3.3m
津波大石	約11.5m	約9.6m	約6.0m

八重山毎日新聞 2012年11月17日（土）

1. Tsunami boulders are useful scientific evidence to know the paleotsunami histories.

2. They are very useful for disaster education purpose.

3. Great interest in the world?

Tsunami smijt met koraal

Binnen tien jaar zal een grote tsunami de kust van de Riukiu-eilanden overspoelen – als de gemiddelde frequentie wordt aangehouden. Grote brokken koraal vertellen hoe dat zit.

Bij de laatste grote tsunami, in 1771, vielen 12.000 doden

NOTE: Some tsunami boulders are now protected and it is prohibited to take sample (or even stand on the boulder) without permission.

Summary

1. We studied boulders on the reef at Ryukyu Islands and discriminated their origin (tsunami or storm waves).
2. **Tsunami boulders were deposited ONLY at Sakishima Islands** and are useful to know the paleo-tsunami histories after the formation of the present reef. The recurrence interval of tsunami is estimated as 150-400 years. Among them, three large events (including 1771 event) might have occurred during 2000 years.
3. New methodology will open the new door for the further development of boulder research.
4. Presence of storm wave boulders (but absence of tsunami boulders) is also very useful to constraint the size of paleotsunamis.

Acknowledgement: I thank to Toshio Kawana, Koji Minoura, Chuki Hongo, Hideki Kawamata, Keitaro Miyazawa, Yosuke Suda, Satoko Ikema, Norihiro Nakamura, Tetsuro Sato, Akifumi Hisamatsu and local peoples at Ryukyu Islands.