INDEPTH IV: International Deep Profiling of Tibet and the Himalaya

The Controlled Source Seismic Project
May-June 2007
Field Report

Version 1.0 prepared January 25, 2008 by Marianne Karplus (mkarplus@stanford.edu) for IRIS-PASSCAL, on behalf of INDEPTH active source PIs, Larry Brown (ldb7@cornell.edu) and Simon Klemperer (sklemp@stanford.edu)

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I. Introduction & Motivation

Project INDEPTH (International Deep Profiling of Tibet and the Himalaya) is a multidisciplinary geophysical and geological investigation of the Himalayas and Tibet. Field projects associated with INDEPTH I, II, and III took place between 1992-2000 and covered Southern to Central Tibet. In summer 2007, the INDEPTH IV project acquired an active source seismic line in NE Tibet, completing the final segment of the INDEPTH profile across the entire Tibetan plateau (Figure 1 shows the relative locations of the four INDEPTH profiles).

Often considered the ideal location for investigating continental collisional tectonics, the Himalayas and Tibetan Plateau have experienced compression and uplift over the past ~55 Ma since the initiation of collision between the Indian and Asian plates. During convergence both plates underwent significant deformation and crustal thickening. Debate continues regarding how Asia has responded to the embedding of the Indian subcontinent with theories including indentor tectonics leading to terrane escape along lithospheric strike-slip faults (e.g. Tapponier and Molnar, 1976) and lower-crustal ductile flow (e.g., Zhao and Morgan, 1987; Beaumont et al., 2001).

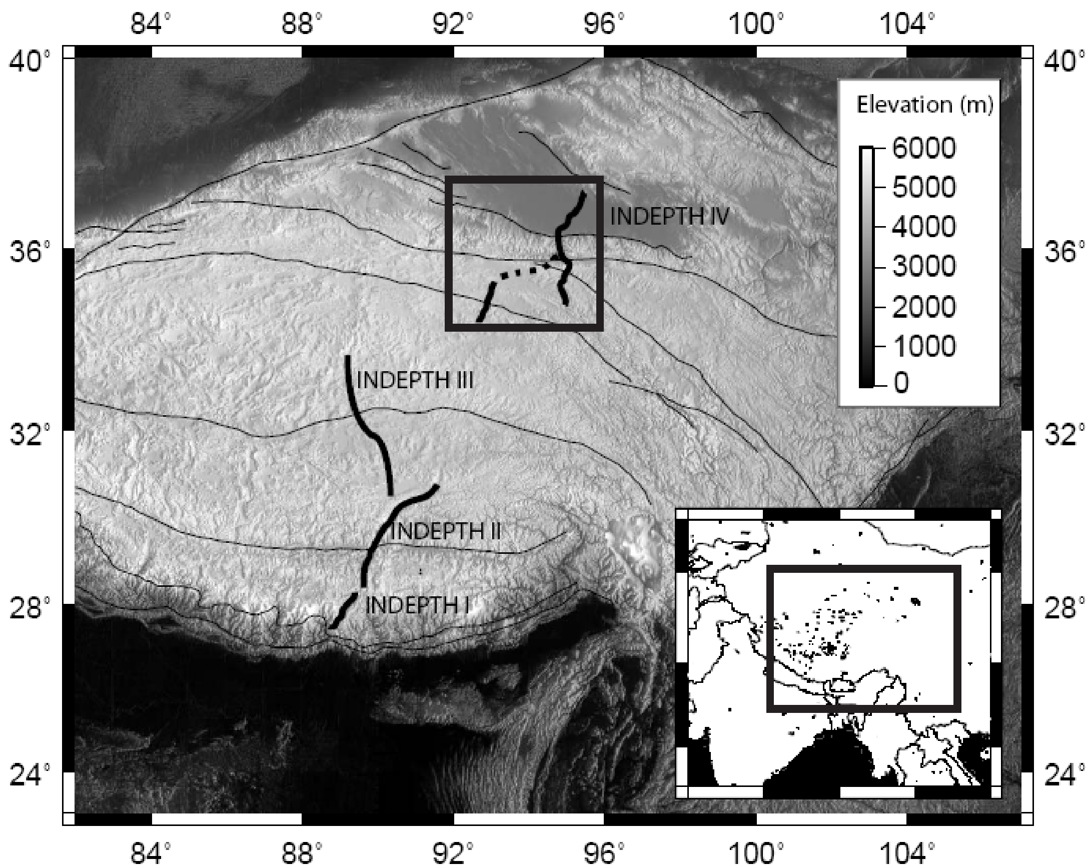

Figure 1. Topographic map showing locations of INDEPTH I-IV profiles spanning Tibetan plateau from South to North.

Previous seismic studies have significantly elucidated the response of Asia to the impact of the Indian subcontinent from Southern to Central Tibet (e.g., Klemperer, 2006). The INDEPTH IV transect across the northeast boundary of Tibet is expected to clarify the subduction of Asian continental crust beneath the Tibetan Plateau along its northern margin and to probe the geometry and depth extent of the Kunlun Fault.

The 270 km active source seismic profile will be augmented by other multidisciplinary aspects of INDEPTH IV including broadband seismic across the Kunlun and Jinsha sutures (2007-2008), magnetotelluric surveys across the Altyn Tagh and Kunlun (2009), geologic field mapping (2008), and gravity studies (2008). This work will improve understanding of continental collisional tectonics, plateau formation, and faulting in compressional regimes.

Chinese institutions involved in the multinational collaboration include the Chinese Academy of Geological Sciences (CAGS), Chengdu University of Technology, and China University of Geosciences. North American and European institutions include Cornell University, Stanford University, GeoForschungsZentrum Potsdam, Missouri, New Mexico State University, Cambridge, Alberta, Dublin Institute for Advanced Studies, and University of Haifa.

II. Seismic Acquisition Methods

Controlled source seismology involves the detonation of seismic explosive charges in deep boreholes distributed along profiles of seismic recording instruments deployed at regular intervals on the Earth’s surface. The seismic waves generated by the charges travel down into the Earth and are reflected and refracted back to the surface from geological interfaces at depth. The seismic instruments record the resulting seismic waves as they reach the surface along the profiles. The time of arrival of the reflections and refractions at the recording instruments will be interpreted by the research seismologist in terms of the distribution of geological boundaries deep within the Earth. The image is used to constrain our understanding of the geological processes that form these deep geological structures.

A. Receivers

The IRIS PASSCAL INDEPTH IV active source seismic experiment employed four different types of receiver spreads (as shown in Figure 2):

1) Wide-angle (WA) deployment of 295 IRIS PASSCAL single channel OYO 4.5 Hz geophones and Reftek “Texan” RT 125 recorders at 650 m spacing

2) Near-vertical (NV) deployment of 655 IRIS PASSCAL single channel OYO 4.5 Hz geophones and Reftek “Texan” RT 125 recorders at 100 m spacing across the central portion of the profile (including the North and South Kunlun Faults and the North Kunlun Thrust Zone)

3) Adjacent deployment of a 1000-channel Sercel cabled spread with 50 m geophone

spacing
4) Overlapping three component (3C) array (48 Geophysical Instrument Pool Potsdam and SEIS-UK short-period and broadband instruments at 5-6 km spacing).

The “Texans” had three different disk capacities – 32 MB, 64 MB, and 128 MB. The 32 MB instruments were deployed as part of the WA spread on the farthest wings of the profile and programmed with sampling rates of 8 ms. The 64 MB instruments made up portions of the WA and NV spreads and were programmed with sampling rates of 4 ms. The 128 MB instruments were part of the NV spread and had sampling rates of 2 ms.

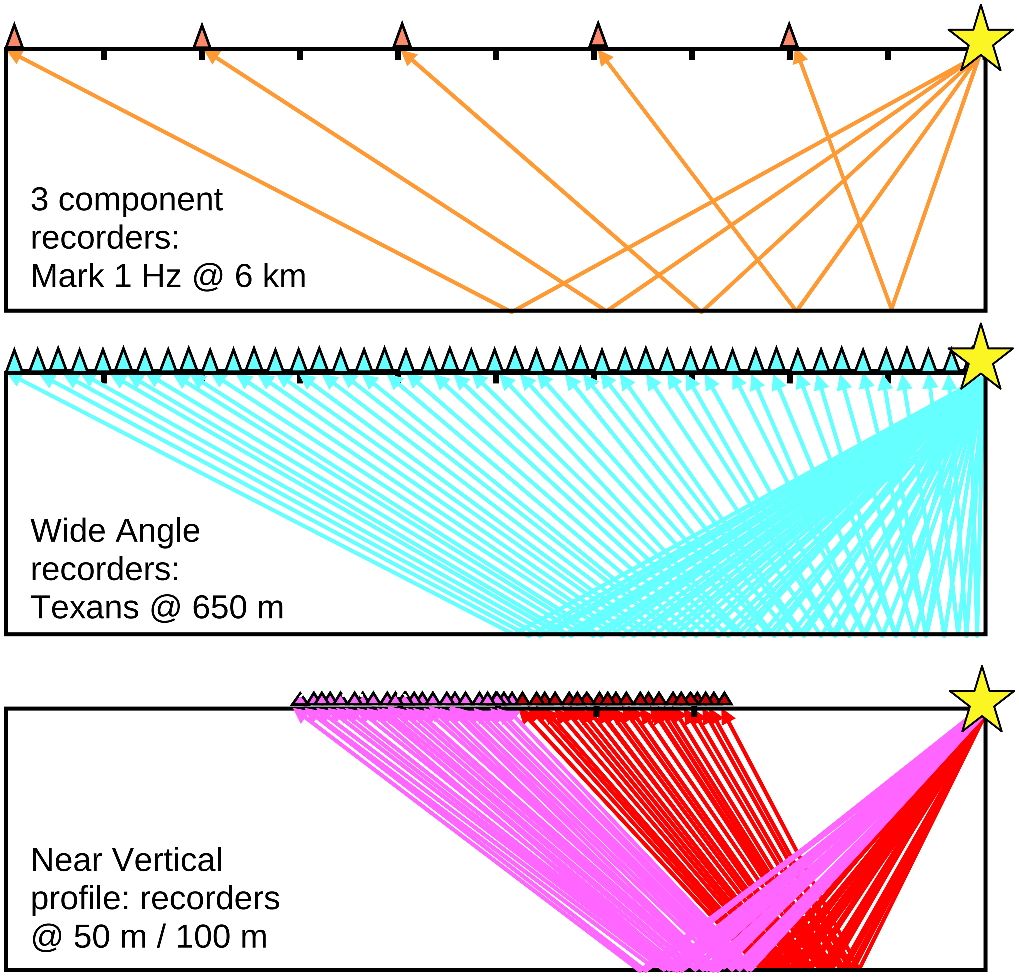

Figure 9. Simplified ray diagram indicating receiver geometry and spacing for the 3-component recorders, wide angle recorders, and near vertical recorders.

Each “Texan” had an instrument number assigned by IRIS PASSCAL. Based on the many iterations of receiver geometries, different receiver locations were assigned different station numbers. These numbers were jettisoned in the final data compilation in favor of the final station numbers based on the following four digit numbering scheme:

BB 1-416 numbered 1 – 416

WA3C 1-415	numbered 1001 – 1415	
WA 2-416	32Mb numbered 2001 – 2416	8 ms sampling
	64Mb numbered 3001 – 3416	4 ms sampling
NV 0020 to 12330	64Mb numbered 4002 – 5233	4 ms sampling
	256Mb numbered 6002 – 7233	2 ms sampling
Sercel channels 1-1000	numbered 8001 – 9000	4 ms sampling

noise strips W1-W14 numbered 9151-9166
shot-break Texans at these shotpoint locations numbered 9200-9299
uphole Texans at these shotpoint locations numbered 9300-9399

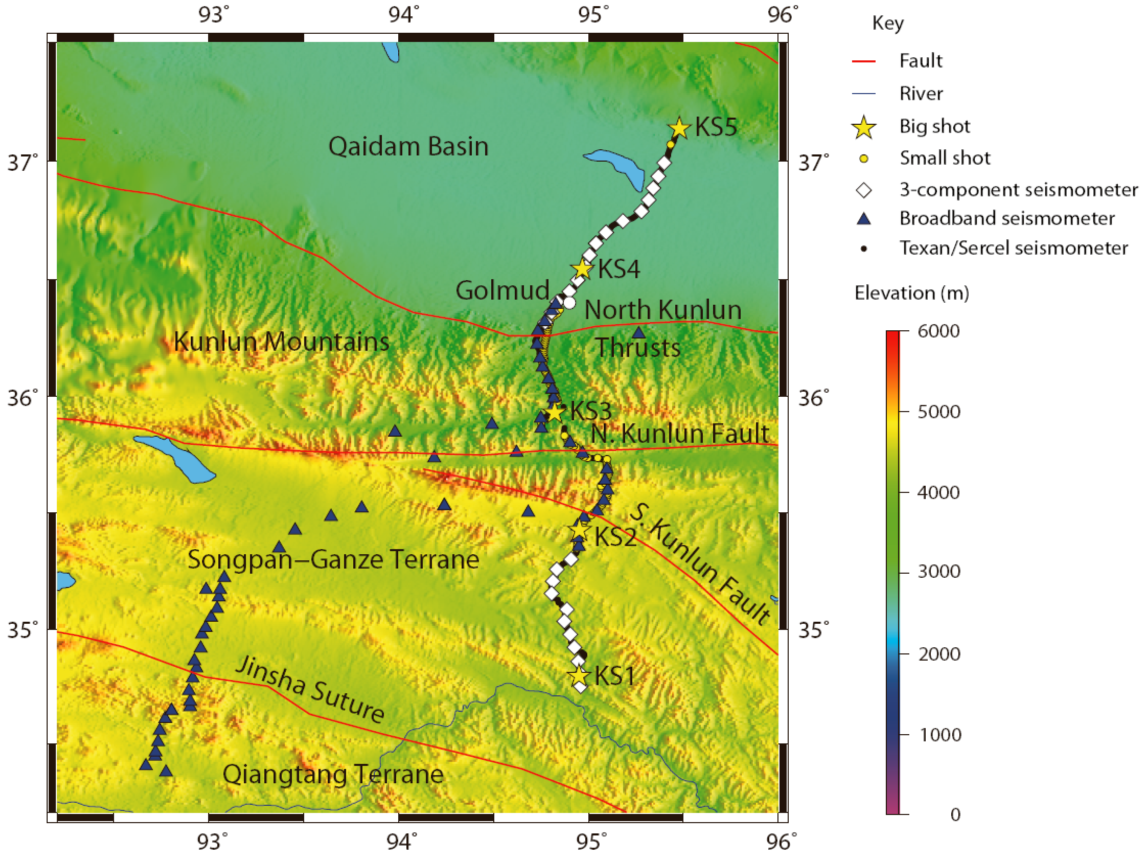

Figure 7. Topographic map of Northeast Tibet showing the locations of INDEPTH IV Texan and Sercel, 3C short-period, broadband instruments, small shots, and large shots.

B. Explosive Sources

Sources included five large shots named KS5 to KS1 (North to South) roughly evenly spaced along the profile containing 2000 kg, 1500 kg, 1000 kg, 1500 kg, and 2000 kg of seismic explosives, respectively. At these sites, explosives screwed together into a single-file cylinder and loaded into holes approximately 6-8 inches in diameter. Each hole reached to ~25-32 m depth and carried ~60-100 kg of explosive. Holes containing explosives were arranged in rectangular arrays designed to have their long axes perpendicular to the profile as much as possible.

There were 105 small shots, each ~60-80 kg explosive, at nominal 1 km spacing along the profile measured from South to North. There was an additional small shot ("KS5-2" or shot point 119) ~5 km south of KS5 because a hole was drilled there and loaded with 100 kg seismic explosive to test the site as a possible KS5 shot location. The site proved to be near to an artesian spring, so KS5 was moved back to its original location further North.

Up to 3 holes of dynamite were detonated at once for a "small shot". Shot 9085 was the only shot that had 3 holes of dynamite (80 kg each).

Most small shots were drilled to near the water table, but there were difficulties with holes collapsing when the drilling rig tried to go deeper than the water table.

All shots were required to have at least 10 m between the top of explosives and ground surface. INDEPTH observers recorded that this was followed consistently.

Explosive sources were numbered according to the following four digit numbering scheme:

Small shots 2 to 118, KS5-1 numbered 9002 – 9119

Big shots KS1 through KS5, plus KS5-1 (several holes at KS5 were detonated later than the initial explosion of KS5 because they could not all be wired at the same time) 9910, 9920, 9930, 9940, 9950, 9952

III. Problems

A. Segmented Shot Loading

For many shot points, the INDEPTH shooting observers noticed the drilling crew using 'segmented loading' to install dynamite in the drill holes. The hole diameters from one of the drilling rigs was sufficiently larger than the explosive capsules that the drilling crew would have had to support the entire weight of the explosives column in order to load one continuous string of explosives. Instead, they would screw several capsules together, throw it down the hole, and then repeat with another string of explosives. Since the blasting caps were at the top, middle, and bottom of the column of explosives, this led to concern that maybe all of the dynamite wouldn't detonate. Shots for which segment loading was witnessed include: 9030, 9032, and 9033.

B. Permissions

We only received permission to put a few receivers/shots in a rectangular region near KS3 and the center of the profile. The region extended from 35 50' to 36 15' N latitude and from 94 45’ to 95 30’ East latitude. The only Texans deployed between NV location 6550 and 6669 were 6554, 6564, 6574, and 6584. This means there is a gap of ~115 Texans in that area. There is also a gap of ~10 shots in that area. Five shots were drilled and loaded but were not allowed to be detonated. Several shots were relocated somewhat West of the main profile.

C. Five “missing” shots detonated after some Texans retrieved

The last shots fired – shots 9074, 9076, 9077, and 9078 – were not recorded by the 32 MB instruments because the instruments were picked up before those shots were fired. These shots were fired late because there was a communication issue – the shots along with 9080 were reported to be drilled when they weren’t drilled. A water well drilling rig was hired especially for the task of drilling these last 5 shots. The holes drilled by this rig were larger than the other holes. 9080 was detonated the afternoon of June 16, and the others were detonated the morning of June 17.

D. Relocated shots

The dGPS surveying was, in some cases, completed before a shot was drilled or a receiver was deployed. We believe that no Texans were deployed more than 10 m from the surveyed location. Most were deployed less than 3 m from the surveyed location (marked by a flag).

Some shots were moved after the location was surveyed. Shot 9092 was moved ~115 m. Shot 9094 was moved ~535 m. Shot 9112 was moved 790 m west.

E. Stolen instruments

Four Texans were found to be stolen during the instrument retrieval. Texans 555 & 560 were the two instruments deployed by Julia's team West of Golmud that were stolen and never recovered. Texans 1125 & 1135 were the two instruments deployed by Karl's team on the plateau, which were recovered later in a shepherd's hut.

F. Texan truck accident

A head-on, fatal (for both drivers) collision between the Texan transport truck and another truck occurred while the Texans were being transported from Beijing to Golmud. The accident is believed to have been at highway speeds and caused significant damage to the vehicles, Texan boxes, and some Texan instruments. All instruments were tested upon arrival in Golmud, and instruments that seemed compromised were not used in the experiment.

After the instruments returned to the U.S., more thorough testing showed that there should not have been any abnormal drift errors. See Appendix A for complete report. The following is the email report from Mike Fort at IRIS PASSCAL:

"All of the Texans were thoroughly tested after they returned from China. I have attached a summary describing the tests performed, and the results of the testing for the PASSCAL Texans. Based on these test results we do not believe that there would have been any abnormal drift errors caused by the accident for the INDEPTH IV data. Let me know if you need any more information.

Mike Fort
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Ph. 505 835 5070
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IV. IRIS PASSCAL Initial Data Processing

Galen Kaip at IRIS PASSCAL cut two or three sixty second gathers for every shot, compiling traces for instruments with each of the 3 sampling rates (2 ms, 4 ms, and 8 ms corresponding to Texans with 128 MB, 64 MB, and 32 MB of disk space). The last shots fired – shots 9074, 9076, 9077, and 9078 – had only 2 gathers because the 32 MB instruments were picked up before those shots were fired. The Sixth Chinese Geophysical Brigade compiled the Sercel gathers with 4 ms sampling for 60 s time windows associated with each shot.

When importing into Landmark PROMAX software, use Remap SEG-Y Header Values with the code "stat_no,,2I,,171/inst_no,,4I,,173/".

V. Directory structure

Data are submitted in standard SEGY format organized in 3 main directories by Texan disk size (128 MB, 64 MB, 32 MB). Each directory contains shot gathers named according to the start time of the gather (5 seconds before the shot time).

VI. References

Beaumont, C., R. A. Jamieson, M. H. Nguyen, and B. Lee (2001). Himalayan tectonics explained by extrusion of a low-viscosity crustal channel coupled to focused surface denudation, *Nature* **414,** 738-742.

Klemperer, S. (2006), Crustal flow in Tibet: geophysical evidence for the physical state of Tibetan lithosphere, and inferred patterns of active flow, Geol Soc Lond Spec Pub 268, 39-70.

Tapponnier, P. and P.J. Molnar (1976). Slip-line field theory and large-scale continental tectonics, *Nature*, **264**, 3190-24.

Zhao, W., and W. J. Morgan (1987). Injection of Indian crust into Tibetan lower crust: A two-dimensional finite element model study, *Tectonics* **6,** 489-504.

Appendix A: Texan drift test results

Document prepared by Mike Fort, IRIS PASSCAL

Test Procedure

The testing of the RT125 and RT125A recorders consisted of three main tests.

1. Environmental chamber test. The Texans were programmed to record three windows per hour, placed in an environmental chamber and connected to a 3 Hz 0.1 V sine wave source. The temperature in the chamber was raised to 60 C for four hours, lowered to -20 C for four hours and then raised back to 20 C. The data were examined for waveform quality and a drift rate less than 24 ms/day (0.3 PPM). This test also tested the basic functionality of the recorders.
2. Analog test. Sine wave signals, with frequencies of 3 and 30 Hz and a shorted input were recorded. The data were examined for waveform quality and correct frequency. Basic functionality was also tested.
3. Oscillator test. The output of the oscillator was measured for 48 hours and the drift rate was calculated for that period. The acceptance criteria for were a standard deviation in the frequency of less than 0.03 Hz and a drift rate less than 8 ms/day (0.1 PPM)

Results

A total of 537 units were tested, 287 RT125 recorders and 250 RT125A recorders. Of the 287 RT125 recorders 33 tested bad, and of the 250 RT125A recorders 18 tested bad. The tables below summarize the results.

Type	(All)

Count of SN	
Status	Total
Bad switch	2
Can not be programmed.	1
Corrupted data during analog test	2
Corrupted waveform during temperature test	2
Corrupted waveforms during temperature test	3
High drift during temerature test	4
High drift rate during oscillator test	1
High power	1
Lost Event Table, Analog Test, removed	1
No Offload, kills box Offload	1
No response. No Comm	1
not in return shipment	2
Oscillator unstable	11
Stopped recording and lost all data during temperature test.	10
Stopped recording during temperature test	6
tested ok	486

Will not boot	3
Grand Total	537

Table 1. Summary of all recorders tested.

Type	RT125

Count of SN	
Status	Total
Can not be programmed.	1
Corrupted data during analog test	1
Corrupted waveform during temperature test	2
Corrupted waveforms during temperature test	3
High drift during temerature test	1
High drift rate during oscillator test	1
Lost Event Table, Analog Test, removed	1
No Offload, kills box Offload	1
No response. No Comm	1
not in return shipment	2
Oscillator unstable	7
Stopped recording and lost all data during temperature test.	6
Stopped recording during temperature test	6
tested ok	254
Grand Total	287

Table 2. Summary of RT125 recorders tested.

Type	RT125A

Count of SN	
Status	Total
Bad switch	2
Corrupted data during analog test	1
High drift during temerature test	3
High power	1
Oscillator unstable	4
Stopped recording and lost all data during temperature test.	4
tested ok	232
Will not boot	3
Grand Total	250

Table 3. Summary of RT125A recorders tested.