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ONSHORE-OFFSHORE WIDE-ANGLE SEISMIC RECORDING NEAR CAPE BLANCO, OREGON

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DATA REPORT ON ONSHORE-OFFSHORE WIDE-ANGLE SEISMIC RECORDING NEAR
CAPE BLANCO, OREGON

By

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Menlo Park, California

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ABSTRACT

This report presents deep-crustal wide-angle seismic reflection and refraction data obtained in the vicinity of Cape Blanco, southern Oregon, in October 1994. As part of a larger U.S. Geological Survey (USGS) initiative to better understand the Cascadia margin, the USGS acquired 760 km of deep-crustal multichannel seismic-reflection profiles on the continental margin of southern Oregon using the R/V Ewing from October 3 to October 7, 1994. Prior to this reflection survey, we deployed two temporary, linear arrays of seismic recorders along east-west transects across the Oregon coast range; each array contained 10 matched REFTEK recorders and stretched landward about 80 km from the coast. Each REFTEK recorder contained an oriented 3-component seismometer and recorded digital data on a large capacity hard disk. By recording signals generated by the Ewing's marine air gun array, having a total volume of 137.7 liters (8400 cu. in.), the arrays of land recorders were designed to (1) image the lower crustal structure near the coast in the vicinity of Cape Blanco, (2) determine whether any significant differences in crustal structure exist across a postulated major crustal shear zone in the vicinity of Cape Blanco, and (3) image the subducting Gorda and Juan de Fuca plates. Nearly 12,300 air gun shots along 7 reflection lines were recorded by 18 land recorders. Air gun signals were recorded at ranges as close as 5 km and as far as 160 km. In this report, we describe the land recording of the air gun signals, discuss the processing of the land recorder data into common receiver gathers, and illustrate the processed wide-angle seismic data. Data quality is generally high; refractions from the upper mantle, Pn, were observed at almost all recorders at sufficient offsets from the Ewing.

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INTRODUCTION

The U.S. Geological Survey (USGS) has recently undertaken an initiative to better understand the crustal structure, tectonics, and earthquake and volcanic hazards in the Pacific Northwest and Cascadia margin (Wells and the Cascadia Working Group, 1993). In this report we describe a deep-crustal onshore-offshore seismic investigation by the USGS in southern Oregon. The USGS acquired approximately 760 km of deep-crustal seismic reflection profiles along seven lines in the vicinity of Cape Blanco, from October 3 to October 7, 1994, using a 20-element air gun array and a 160-channel digital-streamer towed by the R/V Ewing. (The Ewing is a former seismic industry reflection vessel now operated by the Lamont-Doherty Earth Observatory.) Prior to the start of the Ewing cruise, we temporarily deployed two linear east-west trending arrays of 10 REFTEK recorders, each stretching landward about 80 km from the coast. The northern deployment of land recorders was located at latitude 43° 14'N (the latitude of Roseburg), and the other, southern deployment of recorders was centered at latitude 42° 40'N, but angled more southeasterly from Port Orford to Grants Pass (Figure 1). The arrays of land recorders were designed to obtain wide-angle seismic data to allow us to (1) image the crustal structure near the coast in southern Oregon, (2) determine whether significant differences in crustal structure exist across a postulated major crustal shear zone in the vicinity of Cape Blanco, and (3) image the subducting Juan de Fuca and Gorda Plates. Nearly 12,300 air gun signals were recorded by both arrays of seismic recorders.

Geologic Setting

Cape Blanco, in southern Oregon, lies along the Cascadia margin where the Juan de Fuca and Gorda plates subduct beneath the North American continent (Figure 1). Significant differences exist between the forearc structure of the Cascadia subduction zone (CSZ) off central and northern Oregon and that of the southern CSZ off southern Oregon and northern California (Wells and the

Cascadia Working Group, 1993). Cape Blanco lies at the boundary between the northern and southern Cascadia subduction zones.

Off central Oregon the continental margin is aseismic and consists of three parallel, generally north-trending, tectonic elements: (1) an accretionary wedge of offscraped and underplated Eocene to Holocene sediment; (2) the Fulmar terrane, an allochthonous sliver of lower Eocene and older terrigenous sediment that has undergone northward translation in the early Tertiary; and (3) the Siletz River Volcanics, a thick monolithic block of Paleogene and lower Eocene oceanic volcanic rocks that may form a backstop for the accretionary complex (Snively, 1987; Trehu et al., 1994). The continental margin in the northern CSZ has high volcanic productivity. Offshore mapping indicates that the northern CSZ forearc is cut by transcurrent faulting (Goldfinger and others, 1992a, b).

In contrast, the southern CSZ forearc of northern California is seismically active, and it lacks the Siletz River block (Wells and the Cascadia Working Group, 1993). In the southern CSZ, an accretionary wedge of principally Paleogene and younger rocks (Coastal belt of the Franciscan Assemblage) is thrust beneath the Central and Eastern belts of the Franciscan Assemblage, which, in turn, are thrust beneath Mesozoic rocks of the Klamath Mountains. The continental margin of the southern CSZ is characterized by low volcanic productivity. Offshore mapping indicates that the southern CSZ forearc is a single, coherent structural block, uncut by transcurrent faulting (Clarke, 1990; Goldfinger and others, 1992a).

A major E-W trending structural boundary is postulated in the Cape Blanco area, separating the central Oregon forearc from that of the southern Oregon-northern California forearc (Snively, 1987; Clarke, 1990). This boundary is believed to form the southern terminus of the lower Eocene Siletz River Volcanics, the terrane bounding Fulmar fault, and the aseismic central segment of the Cascadia subduction zone. This structure could potentially represent a major segmentation point limiting rupture along the Cascadia megathrust and thus is of interest from the earthquake hazard perspective.

The wide-angle data acquired at Cape Blanco and described here were meant to fill a gap between an existing deep-crustal seismic survey in central Oregon (Luetgert et al., 1992; Brocher et al., 1993; Trehu et al., 1994), and a larger survey at the Mendocino triple junction (Mendocino 1994 Working Group, 1994). The Cape Blanco vicinity of the Oregon margin is virtually aseismic, although it is widely believed that this portion of Oregon will be subjected to a large (magnitude 8 to 9) earthquake sometime in the future (e.g., Heaton and Kanamori, 1984; Hyndman and Wang, 1993; Dragert et al., 1994; Verdonck, 1995). The dip of the subducting Juan de Fuca oceanic plate is important for estimating the geometry of the locked zone of the Cascadia megathrust which it is believed will produce this large earthquake.

DATA ACQUISITION

Ewing Instrumentation and Operations

Using the R/V *Ewing*, the USGS acquired seven deep-crustal seismic-reflection profiles on the continental shelf of Oregon in the vicinity of Cape Blanco from 42° to 43.5°N (Figure 1, Table 1). Lines 1, 2, 3 and 4 were acquired along-strike on transects either parallel or subparallel to the Oregon coast. Lines 1 and 2 were acquired in water depths of about 100 to 200 m and were designed to cross the Fulmar fault and the postulated E-W trending shear zone, respectively. Line 3 was acquired in water depths of about 250 to 1000 m, and was designed to again cross the postulated E-W trending shear zone. Line 4 was acquired seaward of the deformation front of the Cascadia subduction zone in water about 3100 m deep and was designed to image the subducting oceanic crust. Lines 5, 6, and 7 were acquired along dip-lines perpendicular to the Oregon coast and margin. Lines 5 and 6 were run seaward from the State 3-mile limit to beyond the Cascadia deformation front (Figure 1) to sample the crust north and south of the postulated shear zone; during planning for the experiment the lines were lengthened to enhance the onshore wide-angle recording.

All seven deep-crustal seismic reflection lines were acquired using a 20-element, 137.7 liters (8400 cu. in.) air gun array deployed on two large booms and a 4.2-km-long, 160-channel digital streamer (Figure 2). Air gun firing times on the *Ewing* were determined from the air gun fire command time as measured on a Global Positioning System (GPS) Clock. The GPS clock was stabilized using a Rubidium clock accurate to within 1 nanosecond. Origin times of the air gun array are believed to be accurate to within a millisecond. Navigation of the *Ewing* was achieved using a Global Positioning System (GPS) receiver; these coordinates are estimated to be accurate to within 20 m. Files containing smoothed navigation and shot times were transmitted daily from the *Ewing* via e-mail.

The geometry of the air gun deployment from the *R/V Ewing* is presented in Figures 2 and 3. The air gun array, composed of Bolt air guns, was generally towed at depths between 8 and 10 meters. As shown in Figure 2, 8 guns were towed on each side of the ship from large retractable booms that were swung out abeam of the ship. The remaining four air guns were deployed from an A-frame on the stern of the ship. The ship-to-gun distance was staggered to minimize fouling the air guns and to optimally separate the air bubbles created by the individual air guns: the center of the air gun array was towed approximately 39.6 m behind the stern of the ship at a depth between 8 and 12 meters (Figure 2). The width of the air gun array across the beam of the ship was roughly 33.8 m (111 feet) (see Figure 3). The Magnavox GPS receiver for the ship was located above the ship's bridge about 47.8 m forward of the stern of the ship, roughly 87.4 m forward of the center of the air gun array. (The data shown here and on tape have not been corrected for this slight offset.) The sizes of the air gun chambers varied from 145 cu. in. (2.4 liters) to 875 cu. in. (14.2 liters) to provide a tuned outgoing source wavelet (Figure 3).

The *Ewing* sailed from port at Coos Bay, Oregon, at 1715 UTC on JD 276 (1015L on 4 October 1994). Almost immediately upon reaching the open ocean the crew began to deploy the streamer as well as the air gun array. The first air gun shot fired by the *Ewing* was at 0243 UTC on JD 277 and the last air gun shot was fired at 1523 UTC on JD 280. Table 1 summarizes the 9 reflection line segments acquired using the *Ewing*, showing the start and end times and locations

of each line. In order to acquire lines 5 and 6 as soon into the cruise as possible, to enhance the chances for successful wide-angle recording of these lines, most of the reflection lines were acquired out of numerical order. For example, the track line geometry required Line 4, the most seaward of the strike lines, to be acquired in two pieces, Line 4 and 4S. Appendix 1 presents a more detailed listing of the **Ewing** air gun shot times, locations, and field file ID (FFID) numbers, giving these values at 30 minute intervals along the track line. The air guns generally were not fired while the **Ewing** was turning from the end of one line to the start point of another line. A total of 12,283 air gun shots were fired during this 3 1/2 day interval.

Finally, scientists on the **Ewing** acquired a number of ancillary data, including several sonobuoys, during the cruise. These sonobuoys were expendable military hydrophones which self-scuttle after 8 hours. The goal of recording these sonobuoys was to obtain control of crustal velocities along the **Ewing** ship tracks necessary to constrain velocities of the offshore regions of the survey area. Table 5 provides a summary of the locations and times the sonobuoys were deployed. Other geophysical data acquired during the cruise included gravity, magnetic, and 3.5 kHz bathymetry data. Weather data were also recorded on the **Ewing**.

TABLE 1. R/V Ewing Airgun Firing Times and Locations

<u>UCT</u> <u>Yr.Day:HR:MIN:SEC</u>	<u>FFID</u>	<u>Lat. (N)</u> <u>Deg. Minute</u>	<u>Long. (W)</u> <u>Deg. Minute</u>	<u>Line</u> <u>No.</u>	<u>Tape</u> <u>FFID</u>
94+277:02:43:13.596	00103	43 27.6102	124 21.9956	cb01	00001
94+277:07:15:10.487	00876	43 11.1202	124 38.9450	cb01	00774
94+277:10:08:51.208	00104	43 13.3858	124 29.2266	cb05	00775
94+277:20:12:42.245	01854	43 09.6455	125 32.4822	cb05	02525
94+277:20:31:56.944	00102	43 08.1771	125 32.4372	cb04	02526
94+278:00:58:15.485	00864	42 47.8815	125 32.0572	cb04	03288
94-278:01:44:40.833	00101	42 48.9993	125 33.4243	cb06	03289
94+278:12:11:16.762	01746	42 42.5987	124 34.2138	cb06	04934
94+278:13:10:51.908	00103	42 40.4444	124 32.9880	cb06T	04935
94-278:16:53:13.019	00755	42 30.7248	124 52.5357	cb06T	05587
94+278:18:49:43.119	00104	42 31.1803	124 55.0315	cb03	05588
94+279:07:11:22.543	01985	43 17.7285	124 46.7986	cb03	07469
94-279:09:45:57.807	00101	43 13.1471	124 36.9358	cb02	07470
94+279:23:00:06.358	02353	42 13.4499	124 37.1967	cb02	09744
94+280:00:33:10.079	00102	42 14.9724	124 37.2126	cb07	09745
94+280:07:46:42.418	01362	42 17.8625	125 22.4321	cb07	11005
94+280:08:02:23.945	00106	42 18.5793	125 23.6212	cb04s	11006
94+280:15:23:54.110	01380	42 51.7775	125 32.8437	cb04s	12280

Wide-Angle Recording

In addition to serving as the sound source for the deep-crustal seismic reflection lines, signals generated by the air gun array on the **Ewing** were recorded in a wide-angle geometry along two temporary deployments of REFTEK recorders. Each deployment consisted of 10 REFTEKs spaced about 9 km apart beginning at the Oregon coast. The northern deployment stretched 76 km from Seven Devils State Park eastwards to Melrose (just west of Roseburg, Figure 1). This deployment was primarily designed to record reflection line 5, an 86-km-long line trending east-west from just south of Cape Arago. The southern deployment, which trended more NW-SE, ran a total of 94 km from Port Orford to Hugo, north of Grants Pass (Figure 1). This deployment was designed primarily to project offshore to reflection line 6, an 81-km-long line trending WNW-ESE from Port Orford. Air gun signals were recorded at ranges as close as 8 km and as far as 160 km along both deployments. Air gun signals from lines 1, 2, 3, 4 and 7 were recorded in a fan geometry by the REFTEK recorders.

The digital REFTEK recorders deployed, primarily models 07G, consist of five major components (PASSCAL, 1991). These components include the (1) Data Acquisition System (DAS), (2) internal hard disk drive, (3) internal oscillator and external GPS Clock, and (4) 3-component 4.5-Hz seismometers. For continuous recording it was necessary to supplement a small internal battery with an 12-V external battery. Each REFTEK DAS is controlled by a Hand Held Terminal (HHT), which is used to program the DAS, determining such parameters as the start and end times of recording, the sample rate (125 Hz in our case), mode of recording (continuous in our case), and number of channels to record (3 in our case). The GPS receiver clocks had a duty cycle of 5 minutes per hour. For our brief deployment, it was not necessary to program a time to stop recording. Recording was simply halted when the instrument was retrieved.

The REFTEK recorders were deployed along existing access roads on October 1-2 (JD 274 and 275). All were programmed to record 3-geophone components continuously at a sample rate of 125 Hz beginning at JD 276 0000 UTC. Three of the REFTEKs (model 07) had only 340

MByte hard-disks and were programmed to record two-components continuously at 125 Hz beginning at JD 276 at 0700 UTC. The start time for the REFTEK recording was chosen to insure recording of a shot window for a 20,000 lb (9090 kg) explosive charge to be fired offshore Portugal at 0830 UTC on JD 276. [Due to problems in obtaining permission to fire the shot this shot was indefinitely delayed]. All the REFTEKs used 4.5 Hz, 3-component seismometers and were connected to 80 Amp-Hour truck batteries, sufficient to provide continuous recording for 8 days (based on a maximum power consumption of 10 Amphour/day).

Latitudes and longitudes of the REFTEK recorders was determined from either the built-in or auxilliary GPS receivers of the REFTEKs, and represent the average GPS location for the 5.5 days of GPS data recorded at 24 different times a day. Estimated average uncertainties of the latitudes and longitudes are about 50 m. Elevations of the recorders were taken from USGS topographic maps using the initial map coordinates.

The percentage of successful data recovery for the experiment was roughly 88% (not including data lost due to the tampering of N-2). Due to instrument malfunction, Stations N-5 and S-10 failed to record any useful data during the experiment. Station N-2 was tampered with sometime after JD 277 and before its retrieval on JD 280, when it was found with its seismometers pulled out of the ground. Station N-3 failed to start recording until it was visited on JD 277, and failed to record Line 1 and virtually all of Line 5 (successful 79%). Station S1 failed to lock to GPS during the experiment, resulting in a free-running, uncorrected, internal clock and no GPS location fix. Fortunately, and most unusually, the station recorded an air wave arrival with a velocity of 0.334 km/s during Line 6 to a maximum offset of about 22 km. This air wave arrival allowed us to determine the amount of drift which had occurred prior to the acquisition of Line 6, and thus infer the drift rate of the low precision internal clock (about 175 ms/day). Station S7 obtained only one GPS lock during the experiment, when it was first deployed. REFTEKs run on low precision clocks until its predetermined "wake-up" time. After waking up the REFTEKs run on a higher precision clock (drift rate typically <10 ms/day), and is ideally periodically

synchronized with GPS time. For this reason we assume the drift of the higher precision internal clock at Station S7 was negligible during the 4 days of data recording.

Fair weather prevailed for the majority of the survey, with generally clear or partly cloudy skies and winds picking up in the evening. No rain was experienced during the experiment. During our experiment, 7 small earthquakes occurred in the Basin and Range province in Northern California, to the south and east of our arrays (Table 3). The local magnitudes of these events varied from between 0.6 and 1.8. The nearest of these earthquakes was approximately 108 km from the southeastern station of our array.

TABLE 2. REFTEK Station GPS Locations and Elevations

<u>Station No.</u>	<u>Station Name</u>	<u>Latitude (N) Degrees</u>	<u>Longitude (W) Degrees</u>	<u>Elevation (m)</u>
N1	Seven Devils	43.234016	124.386360	10
N2	Coos Co. Forest	43.235151	124.346661	128
N3	Beaver Hill	43.230861	124.267648	42
N4	Noble Creek	43.244370	124.175407	42
N5	Coquille River	43.241188	124.059451	60
N6	Middle Creek	43.245236	123.956843	103
N7	Tioga	43.252014	123.831544	230
N8	Williams River	43.250026	123.708675	285
N9	Long Ridge	43.247500	123.576947	750
N10	Melrose School	43.241766	123.444512	160
S1	Port Orford*	42.737500	124.508333	79
S2	Elk River	42.711690	124.375358	61
S3	Panther Creek	42.698689	124.296421	491
S4	Panther Mtn.	42.687346	124.191169	712
S5	Agness Pass	42.679279	124.092266	788
S6	Rogue River	42.654769	123.969733	667
S7	Bear Camp	42.644503	123.860547	1309
S8	Howard Creek	42.601130	123.754598	909
S9	Golden Wedge Mine	42.602454	123.624577	848
S10	Quartz Creek	42.477815	123.410125	679

*Map location, no GPS lock.

Table 3. Local Earthquakes Reported by the University of Washington During the Reftek Deployment

Date	Time Hr:Mn:Sec	Lat Deg.Min	Lon Deg.Min	Depth, km	Mag	Nst	Azi. Gap	Clo- sest	RMS, sec.	???
1994/10/03	16:32 23.51	42N16.37	121W57.93	10.73	0.6	5/006	166	7	0.07	0.5
1994/10/04	02:36 36.26	42N17.26	121W58.84	10.11	1.1	5/008	149	6	0.03	0.2
1994/10/04	13:01 54.80	42N16.06	121W54.70	00.04	1.8	6/007	170	8	0.12	0.1
1994/10/05	02:44 59.42	42N15.73	121W57.82	10.97	1.3	6/007	178	8	0.03	0.2
1994/10/06	03:36 27.10	42N21.28	122W02.43	05.83	1.3	6/009	142	7	0.10	0.9
1994/10/06	07:24 30.95	42N18.23	121W59.93	09.31	0.9	5/007	127	5	0.05	0.3
1994/10/06	22:41 22.37	42N22.75	122W04.12	04.31	0.9	6/008	154	10	0.11	0.8

DATA QUALITY

The data quality obtained during our experiment was generally high. Higher ambient noise near the coasts of each deployment line was observed, and is attributed to wind and wave action localized to the coast. Station N10 was deployed near Interstate Freeway 5, near Roseburg, and experienced higher than average ambient cultural noise. Spectra indicated that the air gun signal was peaked at about 8 Hz, so we typically used a band-pass filter ramped up between 3 and 5 Hz, flat between 5 and 10 Hz, and ramped down between 10 and 12 Hz.

DATA REDUCTION

REFTEKs digitally recorded the wide-angle seismic data using 1 Gbyte hard-disks in compressed format. After retrieving the REFTEKs from the field, we downloaded the digital seismic data onto DAT tapes in refdump format using both a Sun workstation and a PASSCAL field DAT drive. The procedure followed for the field DAT drive consisted of the following. A power supply or battery and a hand-held terminal (HHT) were connected to each DAS unit, and SCSI cables were connected from the DAS to the field DAT drive. The field DAT drive was also connected to a power supply. For each station a new DAT tape was inserted into the field DAT drive. Using the HHT the DAT tape was then formatted by the following steps: press F5 (Data

Menu), press 5 (SCSI Format), press 1 (Format Tape), and press F10 (Start Procedure). With the HHT and power supply still connected to the DAS, and the SCSI cable still connected to the DAT drive, the REFTEK data on the DAS was then written to DAT tape using the following steps: F5 (Data Menu), press 2 (Copy Data), press 8 (Copy Disk to Tape), and press F10 (Start Procedure). Repeating this procedure resulted in 20 DAT tapes, one each for stations N1-N10 and S1-S10. We attempted to repeat this procedure twice for each station, one using the field DAT drive and the other using the Sun workstation. For some DAS units, however, it was possible to download the data using the field DAT drive. If using a Sun workstation, type `refdump -d /dev/sd5c /dev/rst1`.

The seismic data were then converted to SEG-Y format using a PASSCAL program called `ref2segy` (see Appendix 2). Finally, we converted these SEG-Y data into SEG-Y-formatted, common receiver gathers using PASSCAL program `segygather` (Appendix 2). Common receiver gathers were plotted using ProMAX, after trace equalization, bandpass filter, and linear moveout to a velocity of 8 km/s.

SEG-Y Tape Format

The common receiver gathers generated from the digital REFTEK tapes are stored in a unreduced travel time format. Sixty seconds of data were saved for each trace in the common receiver gather (7501 data samples per trace). The sample interval is 8 msec. All the air gun shots for all the reflection lines (12,283 traces) were saved for each common receiver gather. The common receiver gathers obtained were written in SEG-Y format to an Exabyte tape by the `segygather` program. Data from all three geophone components were converted to SEG-Y format and saved to tape. SEG-Y trace header formats described by Barry and others (1975) were modified slightly, as described in Appendix 3. The header is in EBCDIC format, and the data are in IBM floating point format. Appendix 4 describes how we processed the data using ProMAX. Data for each reflection line can be identified on tape via the tape FFID numbers shown on the right-hand side of Table 1.

DESCRIPTION OF THE DATA

We next describe the REFTEK data for the two major E-W trending lines acquired during the Cape Blanco, Oregon experiment in the order the lines were collected. Figures 5 to 21 present data recorded inline to Lines 5 and 6, linearly reduced to 8 km/s. Figures 22 to 39 present data recorded in a fan geometry for Lines 5 and 6. In these plots we show data recorded by northern stations for Line 6, to the south, and data recorded by the southern stations for Line 5, to the north. Figures 22 to 39 are plotted linearly with regard to FFID, but nonlinear ranges are provided. Figures 40 and 41 show data recorded at two stations for Lines 1 and 2, which trended north-south.

Data quality obtained during the experiment for both Lines 5 and 6 was significantly superior to that obtained in a similar experiment in central Oregon [Brocher and others, 1993], in that coherent arrivals could be traced to ranges as much as 170 km, whereas in central Oregon arrivals could seldom be traced beyond 100 to 120 km. In the vicinity of Cape Blanco Pg arrivals from the crust can be traced to source-receiver offsets as much as 100? km. Weak but coherent refractions having apparent velocities of 9.5 km/s, inferred to be refractions from the upper mantle, Pn, can be traced on many of the profiles for distances up to 30 km. The distance to the cross over between Pg and Pn is about 60 km for stations near the coast, and progressively increases to distances of 100 km as the station location was moved landward.

Strong shear wave arrivals were recorded by stations along the northern REFTEK deployment. These arrivals have apparent velocities between 1.8 and 3.0 km/s, and were best observed by stations nearest the coast. No shear waves were recorded by stations along the southern REFTEK deployment.

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