Appendix B. Capabilities of existing subsidence monitoring instruments

INSTRUMENT \ PROPERTIES	AVAILABILITY	OPERATING PRINCIPLE	DEPTH RANGE	RANGE OF VERTICLE DISPLACEMENT	MANUFACTURER'S SENSITIVITY	ACCURACY	MAXIMUM DOWNHOLE TEMPERATURE: RATED OR (ESIMATED)	MAXIMUM DOWNHOLE PRESSURE: RATED OR (ESTIMATED)	MATERIAL COMPOSITION	OPERATION and INSTALLATION (IMPORTANT FEATURES)	MAINTENANCE RE-QUIREMENTS & ESTI-MATED SERVICE LIFE	SELECTED REFERENCES
WIRE-TYPE BOREHOLE EXTENSOMETER: weight-tensioned: weight anchored; with rotary potentiometer or water-level recorder at surface (USGS compaction meter)	Sinco; user-fabricated (4)	Note (a) Measure vertical-displacement between two markers at depth by comparing results of adjacent installation; access to borehole not necessary but wire must be free to move between borehole and transducer outside well. A straight hole (<1/2° inclination) is desirable to reduce friction (3)	Maximum: 600m; Typical; up to 300m	Total: 25-50mm, resettable with water-level recorder; 2.7m maximum with rotary potentiometer.	±0.3mm	Total 1 to 1.5 mm (3) reported. Note: friction drag at stress reversals may limit total length accuracy to ±3 to ±8 mm (5)	(500° C. (2) above which strength loss may become important); no provision for downhole temperature measurement.	not applicable	wire usually stainless steel; may be plastic coated; typically 1/8 in. AISI 302 stranded aircraft cable	Movement between surface and anchor seen as rotation of pulley at surface; counter-weight at surface maintains constant tension on wire ideally, but friction of wire may affect tension (6)	Weight anchors maybe lifted out of borehole to replace wire; Under severe geothermal conditions, pitting corrosion rate may be 0.15 mm•month. So a 3 mm wire would sever in 1-1/2 years. Note: Due to general corrosion, the wire may last 100 years, given a rate of 0.5g/m^2•day	(1) Toliva, 1970 (2) Phillips and Sykes, 1970 (3) De Loos, 1973 (4) Lofgren, 1969 (5) Riley, 1969 (6) Bull and Miller, 1975 (7) Lofgren, 1961
WIRE-TYPE BOREHOLE EXTENSOMETER; weight-tensioned; with grout or mechanical anchor; dial gauge or sensor at surface	Interfels; user-fabricated (1), (2)	as above	Typical: up to 100m	Total: 10-50mm resettable	±0.5 to 1.0mm	Total: 1.5 to 3mm estimated	as above	not applicable	as above; wire may be encased inplastic tubing	Multiple wire installations possible, but may not be practical in deep holes; see note a; easy to reset range	Anchor and wire system usually not removeable; life under severe geothermal conditions may be 1-1/2 years	(1) Waddell, 1964 (2) Sellers, 1969 (3) Cording et al, 1975
WIRE-TYPE BOREHOLE EXTENSOMETER; spring-tensioned; with grout or mechanical anchor; and dial gauge or micrometer sensor at surface	Terrametrics; Peter Smith; Serata	Wire stretched between anchor at depth and spring-loaded reference point at surface. Movement between surface and anchor seen as displacement of sensing rod contact spring	Maximum: 450m Typical: 15-90m	Total: 90-150mm	±0.03mm	Total: ±0.1mm to 2.5mm reported; Under mining conditions, accuracy of single measurment reported to be ±0.2 to 3mm, while survey accuracy tying in borehole collars was ±6mm	as above	not applicable	as above	Multiple wire installations possible, but may not be practical in deep holes; see note a; easy to reset range. Relatively rugged compared to electrical transducers. Stretch of wire due to change in spring tension added to readout value.	as above	(1) Potts, 1964 (2) Dunnicliff, 1970
WIRE-TYPE BOREHOLE EXTENSOMETER; cantilever tensioned; with grout or mechanical anchor; and cantilever-mounted electrical resistance strain gauge sensor at surface	Terrametrics	Wire stretched between anchor and cantilever spring at surface. Movement between surface and anchor causes bending of cantilever and resistance change in strain gauge	Typical: 150m	Total: 15mm resettable	±0.01mm	Total: ±0.5mm estimated	as above	not applicable	as above	Multiple wire installations possiblem but may not be practical in deep holes. See note a. Sensitive to moisture; zero drift can cause problems	as above; except sensor may require recalibration or replacement at more frequent intervals	(1) Sellers, 1969 (2) Dunnicliff, 1970
WIRE-TYPE BOREHOLE EXTENSOMETER; spring tensioned; mechanical or grout anchor; rotory potentiometer sensor at surface	Sinco	Wire stretched from anchor, over pulley (to which potentiometer is coupled)to spring. Movement between surface and anchor seen as pully rotation	Typical: 100m assumed	Total: 50mm resettable	±0.05mm	Total: ±1.5mm estimated	as above	not applicable	as above	as above	as above	(1) Dunnicliff, 1970
WIRE-TYPE BOREHOLE EXTENSOMETER; cantilever tensioned; mechanical or grout anchor; cantilever-mounted vibrating-wire strain gauge sensor at surface	Telmac	Wire stretched between anchor and cantilever spring at surface. Movement between surface and anchor causes bending at cantilever and changes natural frequency of vibrating wire	Typical: 100m	Total: 50mm	±0.01mm	Total: ±1.5mm estimated	as above	not applicable	Stainless steel wires	as above; but somewhat more resistant to environmental problems	as above	(1) Dunnicliff, 1970
ROD-TYPE BOREHOLE EXTENSOMETER; with mechanical or grout anchor; with dial gauge or micrometer sensor	Irad; Interfels; Terrametrics: Huggenberger Soil Instruments	Movement between anchor and surface appears as translation of top of rod relative to surface; Displacement of top of rod detected by sensor	Maximum: 500m Typical: 30-180m	Total: 10-50mm resettable Add rod lengths as required in extention: in compression, can cut rod as needed	±0.01mm to ±0.03mm	Total: ±0.02mm to ±0.6mm estimated	as above	not applicable	Rod generally stainless steel; occasionally aluminum. May be plastic coated of cased in plastic tube. Anchor usually cadmium plated mild steel, or cast iron. Rod is typically small diameter 6mm solid rod - 17mm pipe.	Note C: Access to borehole not required; but top of rod must be free to move between borehole and transducer. Rod installed in flexible tube if hole unstable and requires grouting. A straight hole (1/2° inclination) is desirable to reduce friction. If multiple installation not practical for deep hole, measure vertical displacement between 2 markers at depth by comparing results of adjacent installations.	Typical rod (pipe) wall thickness is 3mm. Based on pitting corrosion rate of 0.15mm/mo(1). The service life would be about 1-1/2 years. If some pinholes can be tolerated, service life may be as long as 100yrs., based on a general corrosion rate of 0.5m^2/day.(1)	(1) Toliva, 1970 (2) Cording, et al., 1975 (3) Seller, 1969
ROD-TYPE BOREHOLE EXTENSOMETER; with mechanical or grout anchor; with linear potentiometer sensor	Interfels; Sinco; Irad; Soil Instruments	as above	Typical: 30m to 180m	total: 10-150m	±0.01mm to 0.1mm	Total: ±0.2 to ±2mm, estimated	as above	not applicable	as above	as above	as above; Wiper-contacts of potentiometer may degrade and wear and require replacement or recalibration within 1 year.	
ROD-TYPE BOREHOLE EXTENSOMETER; with mechanical or grout anchor; with LVDT sensor	Interfels	as above	Typical: 30m to 180m	Total: 12 mm, resettable	±0.01mm to ±0.1mm	Total: ±0.2 to +2mm estimated	as above	not applicable	as above	as above	as above; except service life of LVDT should be somehat longer than for potentiometer if adequately sealed.	
ROD-TYPE BOREHOLE EXTENSOMETER; with mechanical or grout anchor; with vibrating wire strain gauge sensor	Maihak	as above	Typical: 30m to 180m estimated	Total: 6 to 100mm	±0.003mm to ±0.03mm	Total: ±0.05 to ±1.25mm reported; but friction may make +0.05mm unrealistic	as above	not applicable	as above	as above	as above; except service life of vibration wire strain gauge should be several years	

TABLE 2.11 CAPABILITIES OF EXISTING SUBSIDENCE MONITORING INSTRUMENTS •VERTICAL DISPLACEMENTS• Sheet 2 of 4

PROPERTIES / INSTRUMENT	AVAILABILITY	OPERATING PRINCIPLE	DEPTH RANGE	RANGE OF VERTICLE DISPLACEMENT	MANUFACTURER'S SENSITIVITY	ACCURACY	MAXIMUM DOWNHOLE TEMPERATURE: RATED OR (ESIMATED)	MAXIMUM DOWNHOLE PRESSURE: RATED OR (ESTIMATED)	MATERIAL COMPOSITION	OPERATION and INSTALLATION (IMPORTANT FEATURES)	MAINTENANCE REQUIREMENTS & ESTIMATED SERVICE LIFE	SELECTED REFERENCES
ROD-TYPE BOREHOLE EXTENSOMETER, with mechanical or grout anchor; attached wire at surface with scale readout	User fabricated (1)	Movement between surface and anchor seen as translation of top of rod relative to surface; wire attached to rod goes over pulley and is tensioned by a weight. Elevation of wt or rotation of pulley also are measurements of displacement	Typical: 100m	1m	±2.5mm	Total: ±15mm estimated	as above	not applicable	as above	as above	as above	(1) Howell, Wright, and Dearinger, 1976
ROD-TYPE BOREHOLE EXTENSOMETER, with two concentric rods; mechanical anchors; and dial gauge readout (DOUBLE-POINT BOREHOLE EXTENSOMETER)	Irad; Telemetrics	Inner rod anchored at base of borehole. Outer rod extends only partway down the hole and is anchored. Movement between surface and other anchor seen as translation of top of appropriate rod relative to surface; position of inner or outer rod relative to fixed measuring surface read with dial gauge	Maximum: 15m	Total: 100-300m Can be increased in extension with extension rods by 600m	±0.01	Total: ±0.5mm estimated	as above	not applicable	Outer rod: galvanized steel (Irad); probably 15mm. Inner rod: stainless steel.	See note (c); Hole can be grouted if extensometer tools placed in protective tubes; not for use in cased holes	Probably not recoverable for replacement. Corrosion resistance will be higher for all stainless steel assembly; removal of galvanized coating will be rapid; sealing may impede movement between concentric pipes. Service life probably less than 1 year due to corrosion of outer rod and due to scaling	
PIPE-TYPE BOREHOLE EXTENSOMETER, anchored by own weight, attached wire at surface with water level recorded readout	User fabricated (1), (2), (3)	Movement between surface and anchor seen as translation of top of pipe relative to surface; wire attached to pipe goes over pulley and is tensioned by weight. Elevation of weight or rotation of pulley are also measurements of displacement	Maximum: (3)1200m Typical: 300-600m	Total: 25-50mm resettable	±0.01mm to ±0.03mm	Total: 0.2 to 0.6mm estimated	as above	not applicable	Cast iron (3); low alloy steel possible; pipe typically 50mm to 100mm diameter	Pipe usually installed in metal cased hole, often abandoned well; pipe usually found ~5 to 10m below base of casing. See note (c)	Pipe stands on shoe; can probably be removed for replacement, but with difficulty. Typical wall thickness for pipe cited is 4mm for general corrosion rate of 6g/m•d(4); it would last a maximum of 10 years in a sever geothermal environment.	(1) Fulchner, 1977 (2) Komaki, 1969 (3) Hirono, 1969 (4) Toliva, 1970
MULTIPLE BASE LENGTH EXTENSOMETER, with inductance sensors, mechanical metal anchors	Telmac	Central rod, able to move freely in hole, contains inductance-type sensors. When rod moves relative to concentric anchors, inductance sensors detect relative position of each anchor	50m estimated; Maximum of 1 sensor per meter	Maximum: 125mm	0.01mm	Total and interval: 0.02 mm claimed	50°C	(500 KN/m^2 estimated)	Probably stainless steel	Access to hole not necessary, but instrumented rod must be free to displace toward surface. Will not work in metal casing; probably o.k. if anchors installed outside flexible plastic casing	Central rod containing electronics has no mechanical coupling to anchors, so probably could be replaced. Under geothermal conditions, central rod and electronics housing may suffer pitting and corrosion. Electronics as designed not suitable for geothermal environment; life in non-geothermal environment probably 1 yr. Longer if rod replaced	
MULTIPLE BASE LENGTH EXTENSOMETER, with reed switch sensors; and magnetic markers	User fabricated (1, 2, 4)	Permanent, moveable central rod contains reed switches, at approximately same spacing as magnets anchored outside borehole casing. Reed switches may be paired or single. Rod installed so initially each reed switch approximately opposite magnet. Movement of measuring rod needed to align reed switch with corresponding magnet measured with micrometer. Can replace rods with tape for easier handling	30-70m	Total: 150-250mm Intervals: 150-250mm	±0.02mm to ±0.1mm	±0.1mm(1) reported with rods ±0.15mm(2) with tape	(50°C estimated; possibly higher since reed switches can operate to 200°C)	(700 KN/m^2 estimated based on depth range)	Rod: thin-walled stainless steel tube with precision connectors. Tape: Stainless steel. Brass housing for reed switches	Access to hole not necessary, but instrument must be free to displace toward surface. May be slightly influenced by steel casing and accuracy reduced due to distortion of magnetic field.	Central rod can be withdrawn or replaced but with loss of accuracy. Stainless steel tape or tube would become severely pitted in 1 1/2 years of service, based on pitting corrosion rate of 0.15mm/month. (3) Electronics as designed not suitable for geothermal environment Life probably 1 yr under non-geothermal conditions; longer if rod replaced	(1) Burland, Moore and Smith, 1972 (2) Smith and Burland, 1976 (3) Toliva, 1970 (4) Burland and Moore, 1973

TABLE 2.11 CAPABILITIES OF EXISTING SUBSIDENCE MONITORING INSTRUMENTS •VERTICAL DISPLACEMENTS•

PROPERTIES / INSTRUMENT	AVAILABILITY	OPERATING PRINCIPLE	DEPTH RANGE	RANGE OF VERTICLE DISPLACEMENT	MANUFACTURER'S SENSITIVITY	ACCURACY	MAXIMUM DOWNHOLE TEMPERATURE: RATED OR (ESIMATED)	MAXIMUM DOWNHOLE PRESSURE: RATED OR (ESTIMATED)	MATERIAL COMPOSITION	OPERATION and INSTALLATION (IMPORTANT FEATURES)	MAINTENANCE REQUIREMENTS & ESTIMATED SERVICE LIFE	SELECTED REFERENCES
CHAIN-TYPE EXTENSOMETER, mechanical or grout anchor, with linear potentiometer or LVDT sensor	Soil Instruments; Interfels	Device consists of a linear sensor housing in a steel case, and fixed to a concrete anchor or anchor plate. A moveable rod extends from the sensor case at 2nd anchor, 1 m or more away. Movement between anchored sensor case and 2nd anchor detected by sensor. Extensometers can be coupled by using 2nd anchor of 1st extensometer to anchor sensor case of next extensometer	Typical: 60-100m, but lead wire could extend several hundred m. from last sensor to readout	Maximum: 10mm to 300mm per sensor	±0.1mm to ±1.0mm	Interval: ±2 to 5mm estimated Total: assuming 10 sensors @10 ft centers, ±7 to ±16mm estimated	(0-50°C, estimated)	(1000KN/m^2 estimated)	Probably stainless steel	Generally used in dams or fills. Requires well compacted fill or soft grout around anchors and no casing in hole. Rods may be protected by flexible plastic casing. Only lead wires exit at surface; no access to borehole necessary	Cannot be repaired or replaced. Life limited by sensors; LVDT probably more reliable than linear potentiometer. Life probably 1 year under non-geothermal conditions	
SONDE-TYPE EXTENSOMETER, with induction sensor and metal markers	Telmac; Maihak; Terrametrics; Sinco; Soil Instruments	Probe lowered down hole on cable; when it passes anchored metal marker, current change induced in secondary coil and detected at surface. Depth of marker is length of cable played out	Typical: 75m to 100m; Maximum: 300m	Ideally unlimited; but depends on casing; up to ≈ 17% strain possible, based on typical elastic compressibility of casing	±0.1mm to ±1.5mm	Interval: 1.25 to 5mm reported Total: 5 to 10 mm estimated	up to 110°C	(3000KN.m^2 estimated, based on depth range)	Casing usually plastic. Metal markers may be any common metal. Instrument housing stainless steel	Best when hole within 3° of vertical. Markers anchored outside flexible plastic casing. Access to hole required. Not for use in metal casing	If probe can be modified to take geothermal conditions, will be easy to maintain since removed between readings	
SONDE-TYPE EXTENSOMETER, with 2 or 3 induction sensors; and "casing collars" as markers (CASING COLLAR LOCATOR)	Provided as a service only; by Dresser-Atlas, Schlumberger, and others	Sonde consists of 2 or 3 probes rigidly connected in series. Works like above sonde but senses change in metal thickness at collars; distance between adjacent markers determined by cable played out beteen probe detection upper marker (collar) and lower probe detecting lower marker (collar). Depth of probe also determined by wheel on tool which tracks against edge of casing. Wheel has several attached magnets, and each partial rotation of wheel detected by reed switch tool. With triple sensor data can be calibrated in-situ using known distance between 1 pair of sensors	Maximum: 1500m	Ideally unlimited; but depends on compressibility of metal casing and casing/ground bond	±3mm(4) improved to about ±0.1mmat Gronigen(2)	Interval: ±15mm reported (1) for double; ±3.5mm for triple (2) Total: ±0.05m(2)	(Probably up to 120°C; typical for production logging tools.) At Gronigen(2), induction sensors connected by invar mandrel to minimize temperature effect	(Probably 70,000KN/m^2 maximum typical for production logging tools)	Instrument housing stainless steel. Casing: low-alloy steel, standard oil-well casing	Operates in cased hole. Accessible hole required. Works best in holes where casing collar has a recess to provide sharp signal (2)	as above	(1) Allen, 1960 (2) deLoos, 1973 (3) Allen, 1971 (4) Allen, 1968
SONDE-TYPE EXTENSOMETER, with reed switch sensor (lowered on cable) and magnetic markers	Soil Instruments; Terra Technology; ELE	Probe lowered down hole on cable. When it passes anchored magnetic marker, reed switch closes and detected at surface. Depth of marker is length of cable played out, and is measured with steel tape	Typical: 100m	Ideally unlimited, but depends on casing. Up to 17% strain possible.	±1-2mm(1)	Interval: 1-2mm reported(1); Total: ±2.5mm reported for 30m; ±5mm estimated for 100m. Accuracy limited by steel tape	(Probably up to 120°C as above; Reed switched can tolerate up to 200°C)	(1000 KN/m^2 estimated; based on depth range)	Probe in brass or stainless steel housing. Magnet probably Alnico. May be coated with epoxy(1)	Operates in hole cased with non-magnetic casing. Accessible hole required; Magnets anchored to ground outside casing or attached to flexible casing cemented to ground. Magnets may also be pneumatically forced into ground.	as above	(1) Burland, Moore, and Smith, 1972 (2) Marsland and Quarterman, 1974
SONDE-TYPE EXTENSOMETER, with two reed switch sensors and magnetic markers (lowered on rods)	Soil Instruments;	Probe lowered down hole on coupled rods. Probe consists of two reed switches spaced 0.5-1.0m apart; magnets also spaced at this depth. Depth of marker determined by rod used to lower probe. Distance between adjacent markers determined by rod movement between upper reed switch detecting lower magnet. Incremental rod travel measured with micrometer	30m estimated	Total: as above Interval: 150-250mm	±0.05mm	±2mm estimated ±0,1mm claimed by mfg.	(50°C, estimated)	(300KN/m^2 estimated based on depth)	Stainless steel rods; stainless steel housing	As above; requires hole with minimal curvature since not very flexible	as above	
SONDE-TYPE EXTENSOMETER, with radioactive bullet markers and 2 or 3 gamma-ray detectors (GAMMA-RAY LOGGER)	Provided as a service only; by Dresser-Atlas, Schlumberger, and others	Sonde consists of 2 or 3 probes (usually rigidly) connected in series. Signal is sent to surface when x-ray detector locates bullet. Depth determined by amount of cable played out and rotation of tracking wheel-(see casing-collar locator). Distance between adjacent markers determined by amount of cable played out between upper probe detection of upper bullet and lower probe detection of lower bullet. With 3 detectors, can use 1 pair for in-situ calibration	1500m	Unlimited because bullets outside casing in formation	±0.1mm	Depends on logging rate; works best at slow rate (1.5m/min(1)or less(4)). Accuracy probably higher than for casing collar locator once strain exceeds elastic limit of casing; Interval: ±30mm error in 2-detector tool(2) can be reduced to ±3mm error in 3-detector tool(1); Total: ±10 to 120mm(1)	(200°C, estimated; typical for x-ray logging tools) Tool cooled with dry ice (3)	(140,000 kN/m^2; typical for x-ray logging tools)	Bullets are 10µ Curie Cesium 137(1) at Gronigen and 1-6µ Curie in Japan(4) Invar housing(1)1cp	Operates in cased, open hole; since bullets are shot into formation with perforating gun, best to them install before casing. Otherwise, to prevent leakage, only production zone can be marked. May be impossible to place bullets in hard formations such as anhydrite and dolomite.(1) Can install free-hanging casing length inside completed borehole with R/A bullets welded at known intervals to use as in-situ calibration for tool. In Japan, welded buttons to production casing to get compaction of casing as well as ground(4).	If tool can be modified to meet geothermal environment, should be easy to maintain since portable. Some problem may arise if R/A bullets are dislodged or diffuse into formation	(1) deLoos, 1973 (2) Allen, 1969 (3) Allen, 1977 (4) Sano, 1969 (5) Allen, 1971
SONDE-TYPE EXTENSOMETER, with latching pawls to detect casing collars	Soiltest; Sinco; Soil Instruments; Geotesting	When probe lowered down through small dia,. coupling into larger diameter casing, pawls will lock if pulled upward against smaller x-section. Depth measured on graduated tape at these x-sections	Typical: 100m	Total interval: 3-6% vertical strain; limited to allowable movement per coupling	±1 to ±3mm	Interval: ±10m estimated Total: ±40mm estimated Best when hole within 25° of vertical	(50°C, estimated)	(1000 kN/m^2 estimated; but should operate if some leakage occurs)	Chrome/brass or galvanized steel	Requires cased hole with telescoping tubing and collars which have a different I.D. from casing. Latching mechanism released when probe hits hole bottom, allowing withdrawal. Requires applied upward force at regular intervals to detect collars	Tool has moving mechanical parts; although portable, may be difficult to modify for geothermal conditions	

PROPERTIES / INSTRUMENT	AVAILABILITY	OPERATING PRINCIPLE	DEPTH RANGE	RANGE OF VERTICLE DISPLACEMENT	MANUFACTURER'S SENSITIVITY	ACCURACY	MAXIMUM DOWNHOLE TEMPERATURE: RATED OR (ESIMATED)	MAXIMUM DOWNHOLE PRESSURE: RATED OR (ESTIMATED)	MATERIAL COMPOSITION	OPERATION and INSTALLATION (IMPORTANT FEATURES)	MAINTENANCE REQUIREMENTS & ESTIMATED SERVICE LIFE	SELECTED REFERENCES
SONDE-TYPE BOREHOLE INCLINOMETER; with pendulum and LVDT sensor	Galileo; Dames and Moore	As probe inclines, pendulum remains vertical. The LVDT measures the displacement of the bottom of the pendulum relative to the instrument case. Depth determined by amount of cable played out at measuring point.	300m estimated	12°	±1 min	±10 min estimated	(50°C, estimated based on typical electronics)	(3000 KN/cm^2, estimated based on depth)	Probably stainless steel housing; casing usually grooved PVC.	To get orientation, must install in grooved or square casing, survey initially for spiral; for best results, casing should be telescoping if cemented or keyed to surrounding ground. Casing may be inserted inside flexible grouted casing. Take readings at intervals corresponding to tool length.	Probe temporary; if it can be modified to meet geothermal conditions, it should be easily maintained. Scaling and distortion of casing groves may limit life. Casing materials now used not suitable for geothermal environment.	
SONDE-TYPE BOREHOLE INCLINOMETER; with pendulum and linear potentiometer sensor	Sinco	As probe inclines, pendulum remains vertical. Pendulum contacts resistance element fixed to case. Resistance varies with angle between pendulum and instrument case. Depth determined by amount of cable played out at measuring point.	300m	12° - 25°	3 min	±20 min estimated	(as above)	1400 KN/m^2	Probe has brass housing, casing usually aluminum or plastic	as above	as above	Wilson, 1962
SONDE-TYPE BOREHOLE INCLINOMETER; with pendulum and servo-accelerometer	Terra-Technology; Geo-Testing; Sinco	As probe inclines, pendulum remains vertical. This system measures force required to return pendulum to initial alignment in probe. Depth determined by amount of cable played out at measuring point.	300m	Typical: 25° 45-90° available	±10 sec	±1 min reported (1)	Typical: 50°C, up to 90°C available	Typical: 3500 KN/m^2 up to 140,000 KN/m^2 available	Probe has stainless steel housing; wheel may be aluminum, stainless steel, or hard plastic; cable cased in hard polyurethane or neoprene.	as above	as above	(1) Brownwell, Ryan and Toth, 1971
SONDE-TYPE BOREHOLE INCLINOMETER; with pendulum and air pressure device	TerraTech, developmental	As above except: Tilt measured by pneumatic force (air pressure) required to return pendulum to original alignment in probe.	100m estimated		±35 sec	±3 deg estimated	(50°C estimated)	(1000 KN/m^2 estimated	Probably stainless steel housing	as above	as above	Dunnicliff, 1970
SONDE-TYPE BOREHOLE INCLINOMETER; with cantilevered pendulum and vibrating wire strain gauges	Maihak; Telemac; Geonor; ELE	Cantilever with weight at unsupported end bends as probe tilts. Bending of cantilever measured by vibrating wire strain gauge. Depth determined by amount of cable played out at measuring point.	300m estimated	Typical: 6-30°	±30 sec - ±2 min	±3 to 4 min reported	(50°C estimated based on typical electronics)	(3000 KN/m^2, estimated based on depth)	Probably stainless steel housing. Casing usually grooved, PVC.	as above	as above	
SONDE-TYPE BOREHOLE INCLINOMETER; with cantilevered pendulum and bonded electrical resistance strain gauges	Soil Instruments: Soiltest	Cantilever with weight at unsupported end bends as probe tilts. Bending of cantilever measured by electrical resistance strain gauges. Depth determined by amount of cable played out at measuring point.	200m	5° to 30°	±15 sec to ±40 sec	±1 min(1) reported for shallow depths	(as above)	(2000 KN/m^2, estimated based on depth)	Chrome plated brass or stainless steel housing; neoprene sheathed cable, stainless steel wheels.	as above	as above	(1) Kallstenius and Bergau, 1961
SONDE-TYPE BOREHOLE INCLINOMETER; with pendulum, compass and camera	Sperry Sun; Schlumberger	As probe inclines, pendulum remains vertical. Camera photographs pendulum position relative to compass fixed to case. Depth determined by amount of cable played out at measuring point.	Deep holes more than 6km	2° to 130° available			Maximum: 315°C for 5hrs; with special instrumentation; Typical: 175°C	140,000 KN/m^2	Probably stainless steel housing.	Instrument determines both orientation and tilt; camera operated by timer; accuracy of depth measurement associated with angle measurement will be low unless used as a single-shot device.	Probe temporary; if can be modified to meet geothermal conditions, should be easily maintained	
SONDE-TYPE BOREHOLE INCLINOMETER; pendulum, linear potentiometer, compass and rotary motor	Eastman	For compass orientation, rotary motor rotates mirror until indicator facing north. For angle from vertical as probe tilts, pendulum remains vertical. Pendulum contacts resistor fixed to case. Resistance varies with angle between pendulum and instrument case.	450m - 540m	more than 30°; can used at any angle	1° for tilt; 2° for orientation		(50°C estimated)	6300 KN/m^2	Chrome plated bronze case	Determines inclination and orientation; device also contains TV camera	as above	
SONDE-TYPE BOREHOLE INCLINOMETER; with gyro-compass camera, and pendulum	Service tool only; by Sperry Sun, Schlumberger	As probe inclines, pendulum remains vertical. Camera photographs pendulum position relative to gyro-compass, fixed to case.	6.2km reported; maximum range probably 9km	2° to 90°		±15 min tilt; 1° to 3° orientation	190°C reported, with thermal shield for up to 11.5 hrs.	(112,000 KN/m^2 estimated, based on depth and muds reported)	Housing K-Monel	Determines inclination and orientation	as above	Oil and Gas Journal, 1971
SONDE-TYPE BOREHOLE INCLINOMETER; with needle-pointed pendulum and punchable chart	Totco	as probe inclines pendulum remains vertical. At pre-set time point of pendulum punched chart fixed to probe, giving inclination of probe. Depth determined by amount of wire-line played out.	6-10Km estimated	7, 14, 21 deg	8 min	15 min estimated	Special models available for warm(<150°C and hot(<300°C estimated) holes.	(100,000 KN/m^2 estimated, based on depth)	Probably stainless steel housing	Make reading at one depth only - gives tilt only - not orientation. Must be retrieved to determine tilt. Tilt simply determined by examining chart with magnifying glass, will operate in any type of hole, cased or uncased.	as above	
FIXED BOREHOLE DEFLECTOMETER with cantilever mounted electrical resistance strain gauge sensors	Telemetrics	Steel tubes anchored in hole and connected to adjacent tubes by cantilever. Angular movement between two tubes causes cantilever to bend. Bending sensed by strain gauges.	54m with 6m intervals between cantilevers		±3 sec	±20 sec	50°C	(540 KN/m^2 estimated based on depth)	Tubes are stainless steel	Designed for use in uncased hole but could be installed in flexible casing. Orientation must be determined when installed	Permanent; may be impossible to recover or repair; electronics will require modification for geothermal environment; stainless steel housing may leak after several years service, due to pitting or corrosion.	
FIXED BOREHOLE DEFLECTOMETER with inductive sensor	Interfels	Steel tubes anchored in hole and connected by tensioned wire. Position of wire changes as angular movement between tubes occur. Movement detected by inductive sensors	54m with up to 8 measuring elements	35min/element; resettable	±2 to ±20 sec	±1 to 3 min estimated	(50°C estimated)	(540 KN/m^2 estimated based on depth)	Probably stainless steel housing	as above	as above	
FIXED BOREHOLE DEFLECTOMETER with pendulum, electrical contacts with micrometer	SGI	Pendulum remains vertical as probe tilts. When tilt exceeds a preset value, pendulum has swung far enough to touch electrical contact and complete circuit. Micrometer can be turned from surface to deflect pendulum to determine angle	10m estimated	0 - 1 deg. to several degrees(1)	±6 min to ±7 sec	± 3 deg estimated	(50°C estimated)	(100 KN/m^2 estimated based on depth)	Probably stainless steel housing	Install in flexible tube. Determine orientation when instrument installed. Requires mechanical connection between surface and instrument	as above; probably not suitable for geothermal environment	(1) Kallstenius and Bergau, 1961