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PRELIMINARY INFORMATION

MEMORANDUM

September 24, 1982

TO: H. P. Ross

FROM: W. R. Sill

SUBJECT: Initial results from self-potential survey at Raft River

On September 20 to 22 a limited self-potential survey was conducted at the Raft River geothermal site. The purpose of this survey was to investigate the nature of the self-potential in the vicinity of the reinjection well (#5) before and after a short term reinjection test. Prior to the test, north-south and east-west lines were surveyed in the vicinity of well 5 (Figure 1). The station spacing was 100 m and about 7 kilometers of line were run. After the test had been underway for about 24 hours, about 4 kilometers of the lines were remeasured. The remeasurements were intended to show up any changes that might have taken place due to the reinjection of fluid into the fracture system.

Previous self-potential model studies of this type of a test (reinjection at a rate of 150 gallons per minute) showed that under favorable conditions a change in self-potential of up to a few hundred millivolts (negative) might be generated. These model calculations assume that the flow and pressure field has reached a state of equilibrium. The time necessary to reach equilibrium at Raft River is not known to me. Due to the shortness of the test, the remeasurements had to be made after only 24 hours.

Some of the results are shown in Figures 2 and 3. Figure 2b shows the measured potentials along lines 1 and 2 before and after 24 hours of reinjection. The changes in potential are shown in Figure 2a. North of well 5 there is a suggestion of a negative bias of about -5 millivolts. Figure 3 shows the data for line 4 which goes to the east past well 4. Once again there is a suggestion of a negative bias.

My experience with self-potential surveys indicates that careful resurveys can often be made with errors in the neighborhood of 5 millivolts. This is about the same magnitude of some of the changes noted in the survey so the bias, if there, is just at the level of the noise. It should be noted that this survey was run during an active geomagnetic period and the temporal noise was large and careful averaging of the measurements in the field was necessary. Future measurements at this site should be carried out with a telluric monitor.

One of the outstanding questions has to do with the nature of the flow established during this short test. If 24 hours at 150 gallons per minute is long enough to establish a "steady state" flow regime then perhaps the results given above indicate the magnitude of the resulting self-potential effects. It should be noted that most of the self-potential is generated by the flow in the material surrounding the fractured region.

Bill

Bill Sill

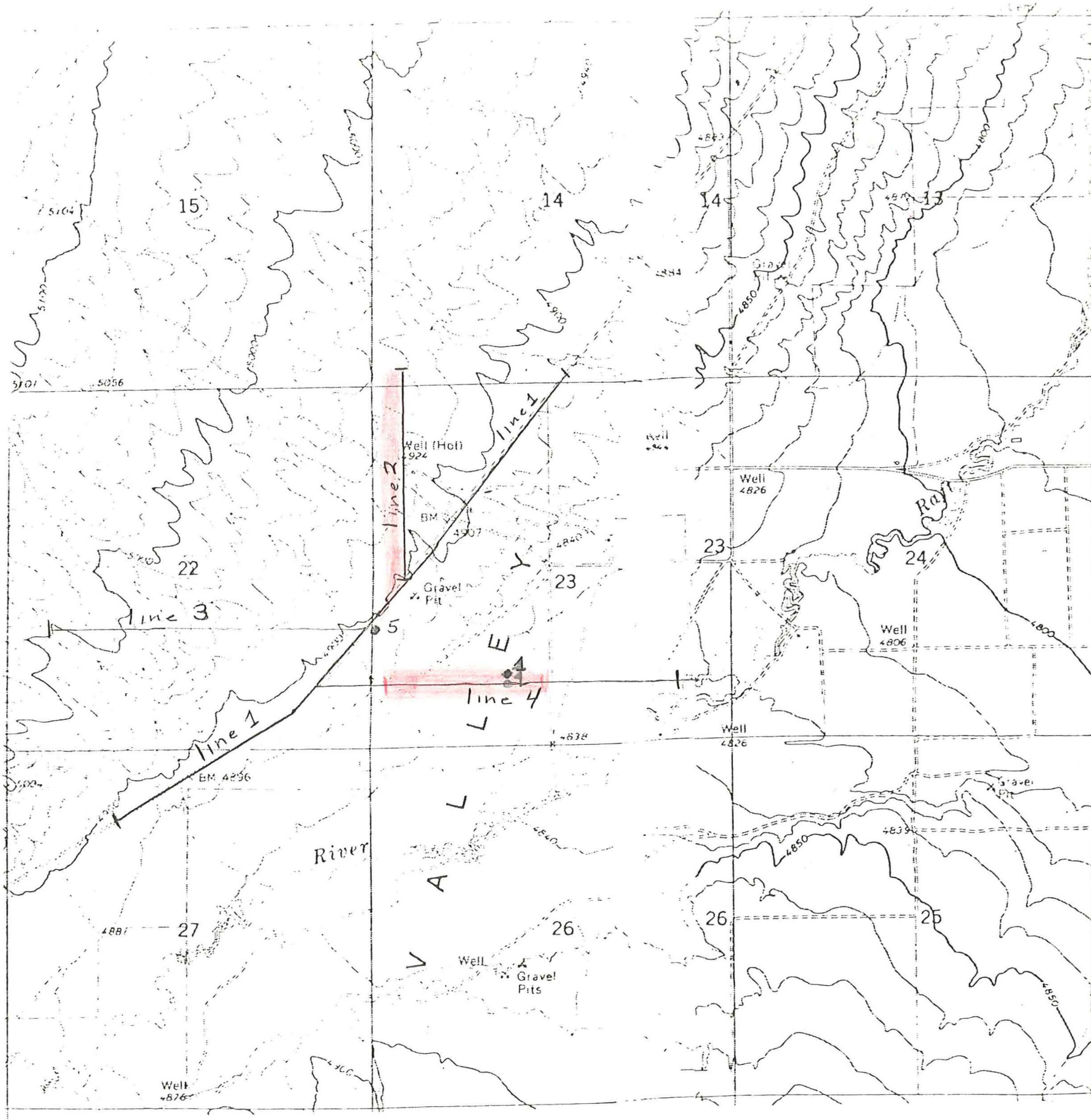
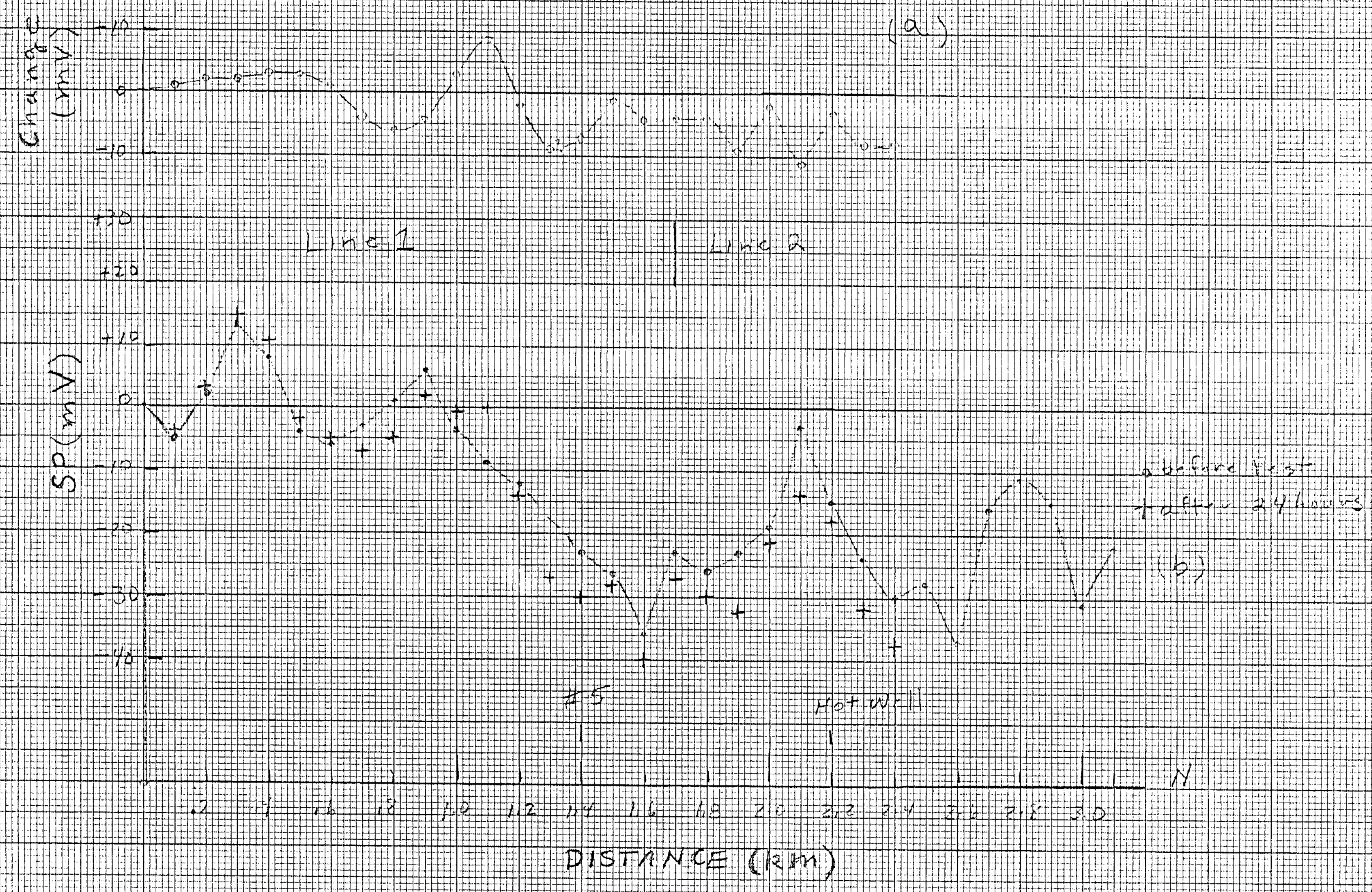


Figure 1
self-potential survey lines, Raft River Id.



Change (mV)
(a)
Line 1
Line 2
SP (mV)
before test
after 24 hours
(b)
#5
Hot Well
N
.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0
DISTANCE (km)

Figure 2.

F

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1510

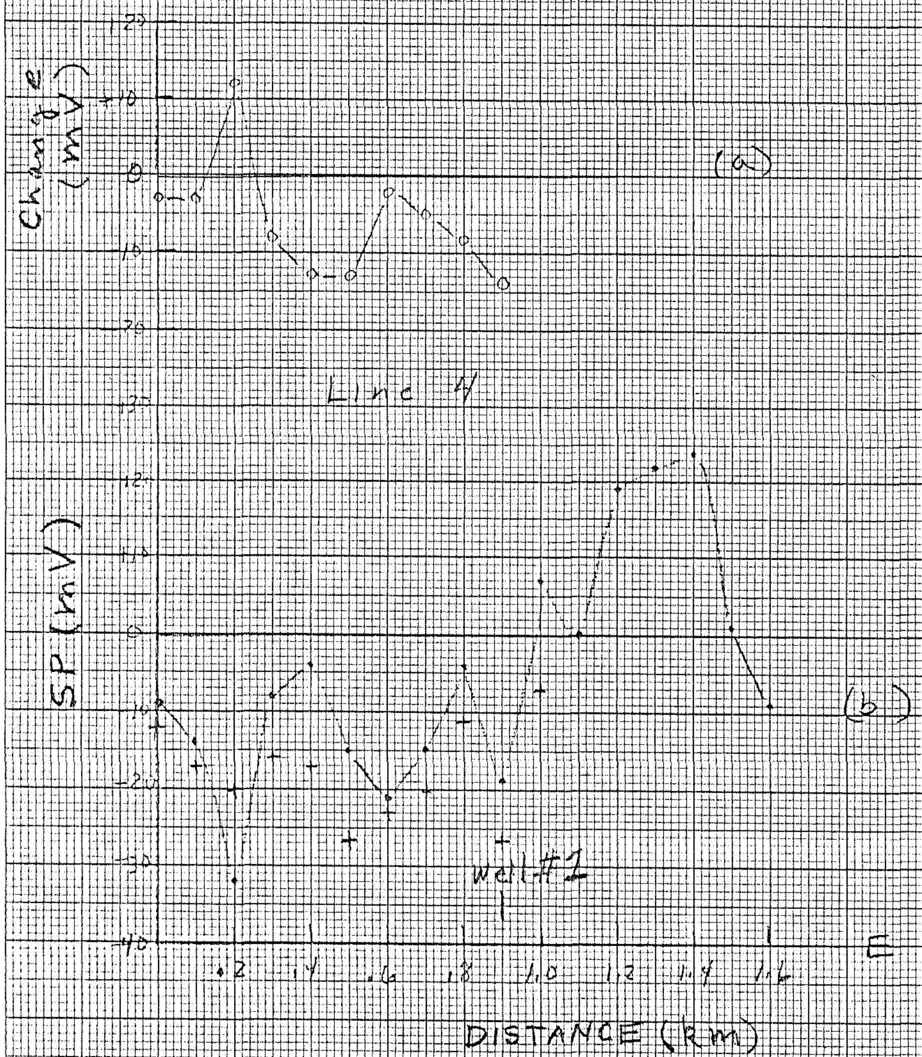
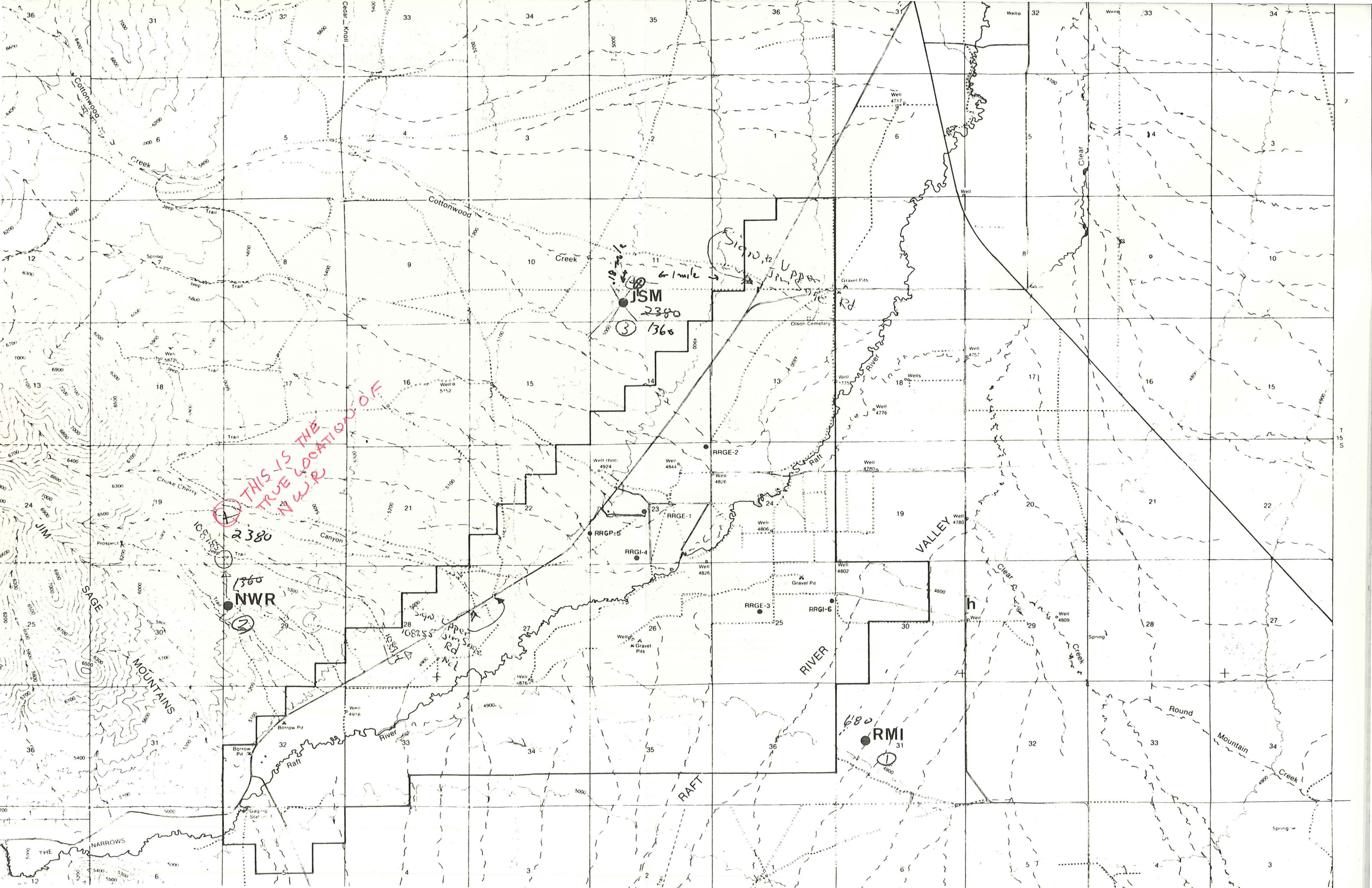


Figure 3


JSM
NWR
RMI
THIS IS THE TRUE LOCATION OF NWR
2380
1360
680
RRGE-2
RRGE-1
RRGP-5
RRGI-4
RRGE-3
RRGI-6
JIM SAGE MOUNTAINS
RAFT RIVER VALLEY
Cottonwood Creek
Choke Cherry Canyon
Round Mountain Creek
Clear Creek
Raft River
THE NARROWS
Cedar Knoll
Olson Cemetery
Gravel Pits
Gravel Pit
Borrow Pit
Gaging Station
Jeep Trail
Prospect
Spring
T 15 S

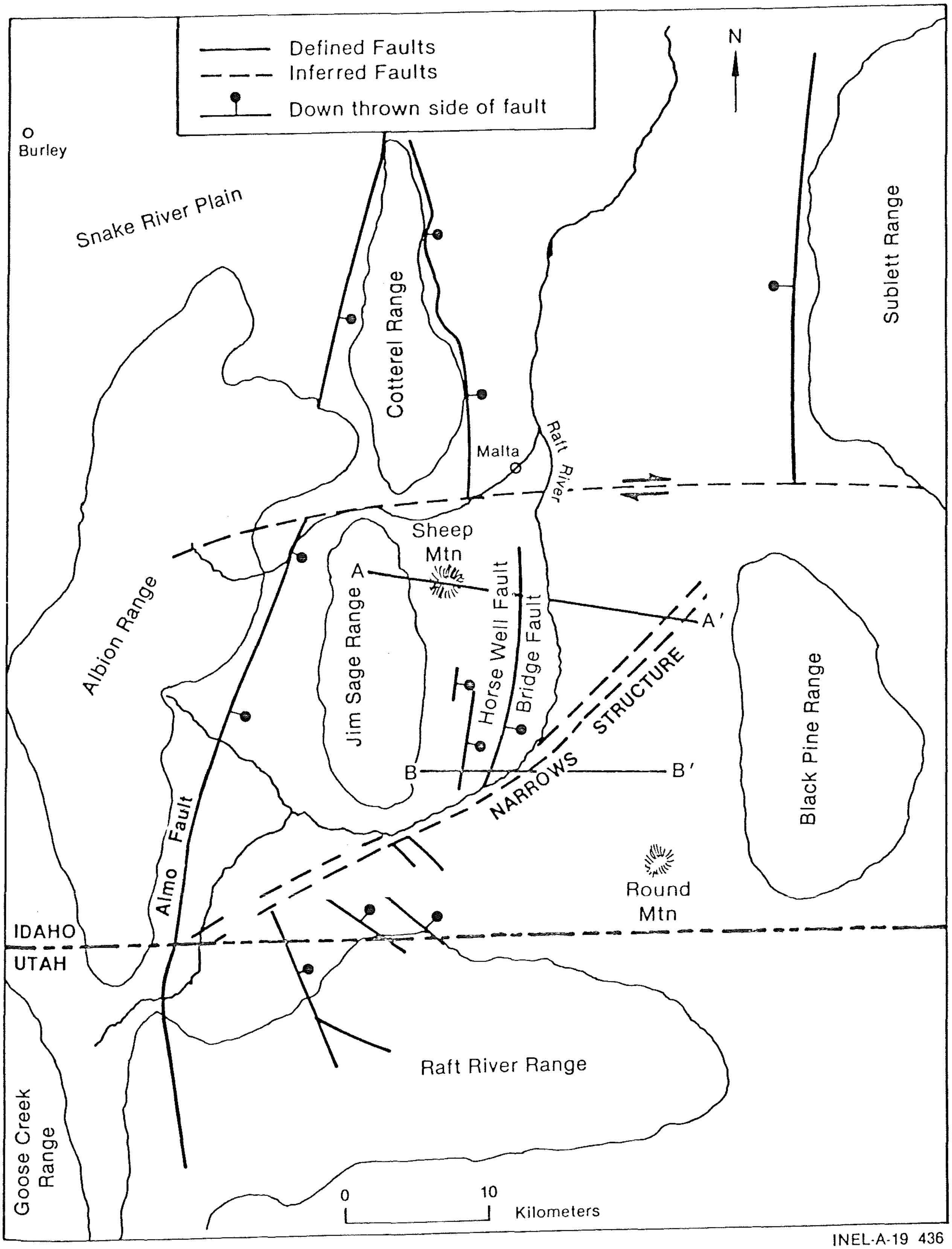


Figure 1 Raft River Valley and major structural features adjoining the valley.

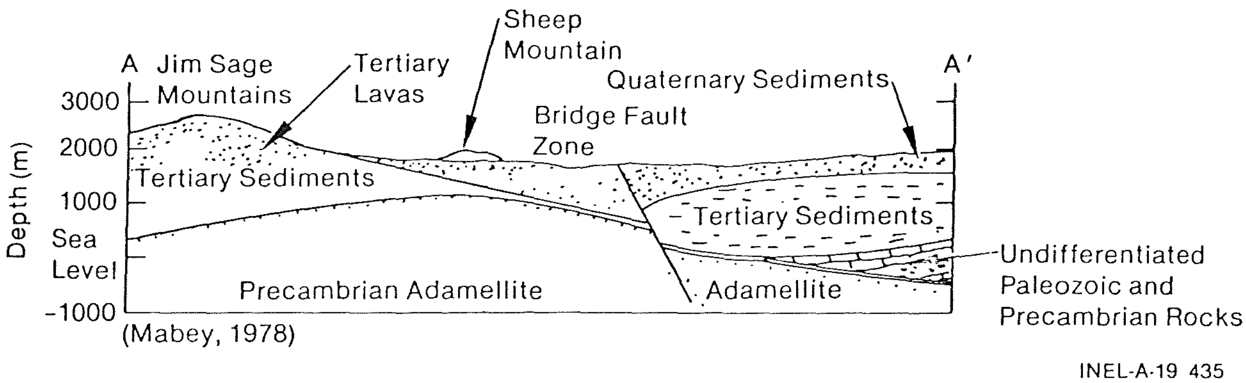


Figure 2a. An early interpretation of the Bridge Fault Zone.

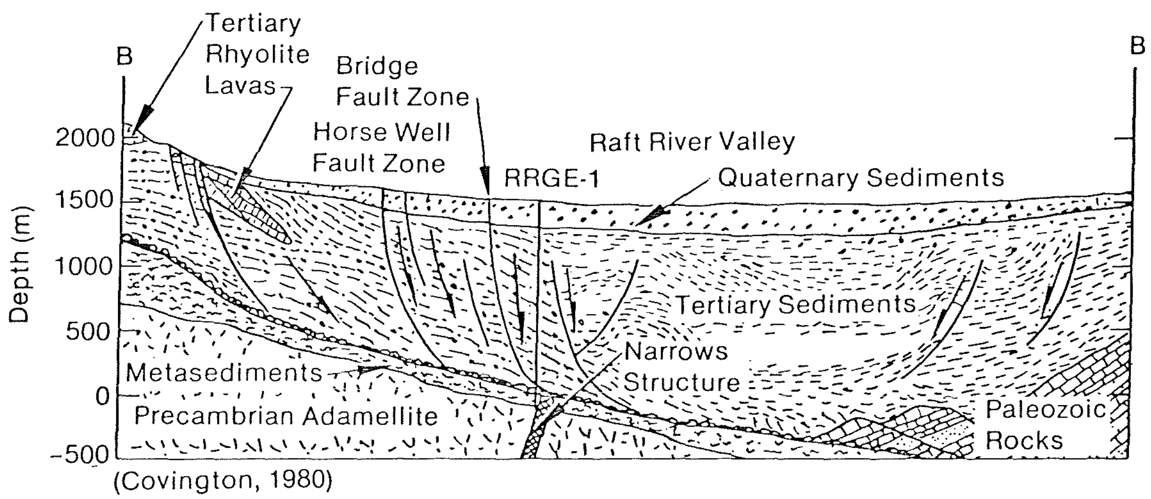


Figure 2b. A later interpretation of the Bridge Fault Zone illustrating no displacement of the basement.

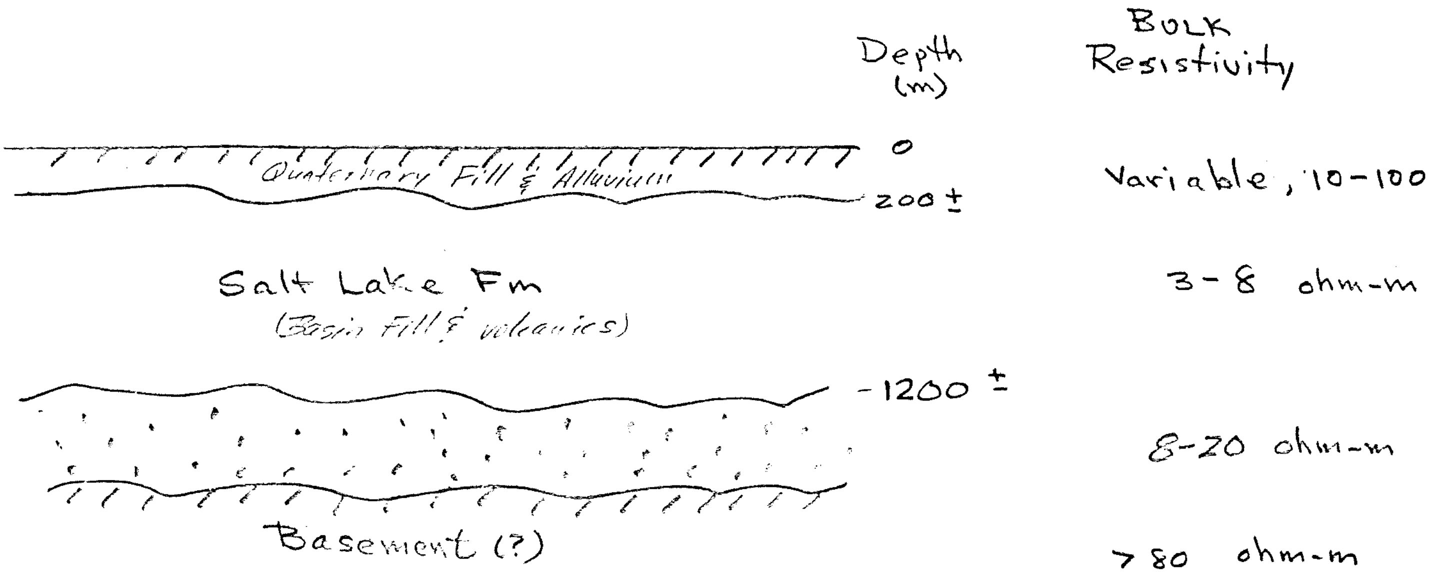
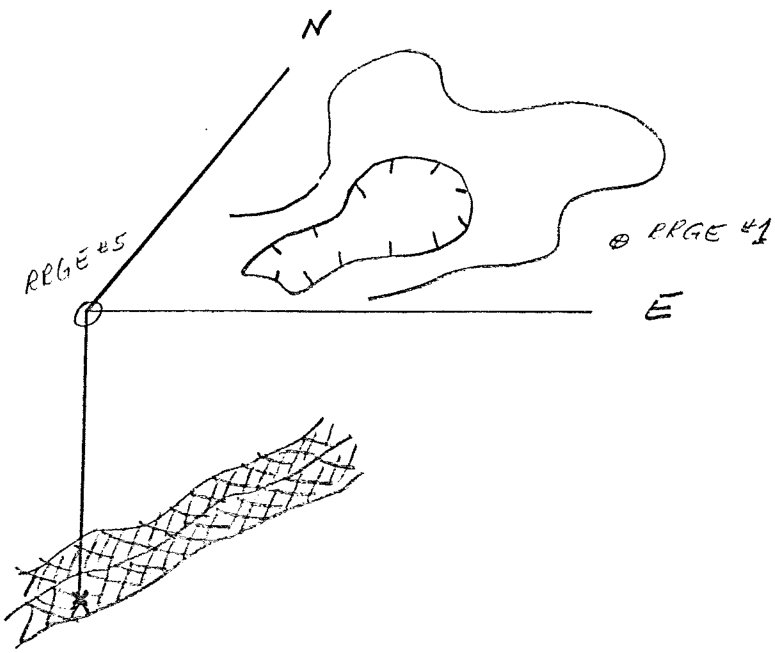


Fig. 3a



BURIED ELECTRODE STUDY

Fig. 3b

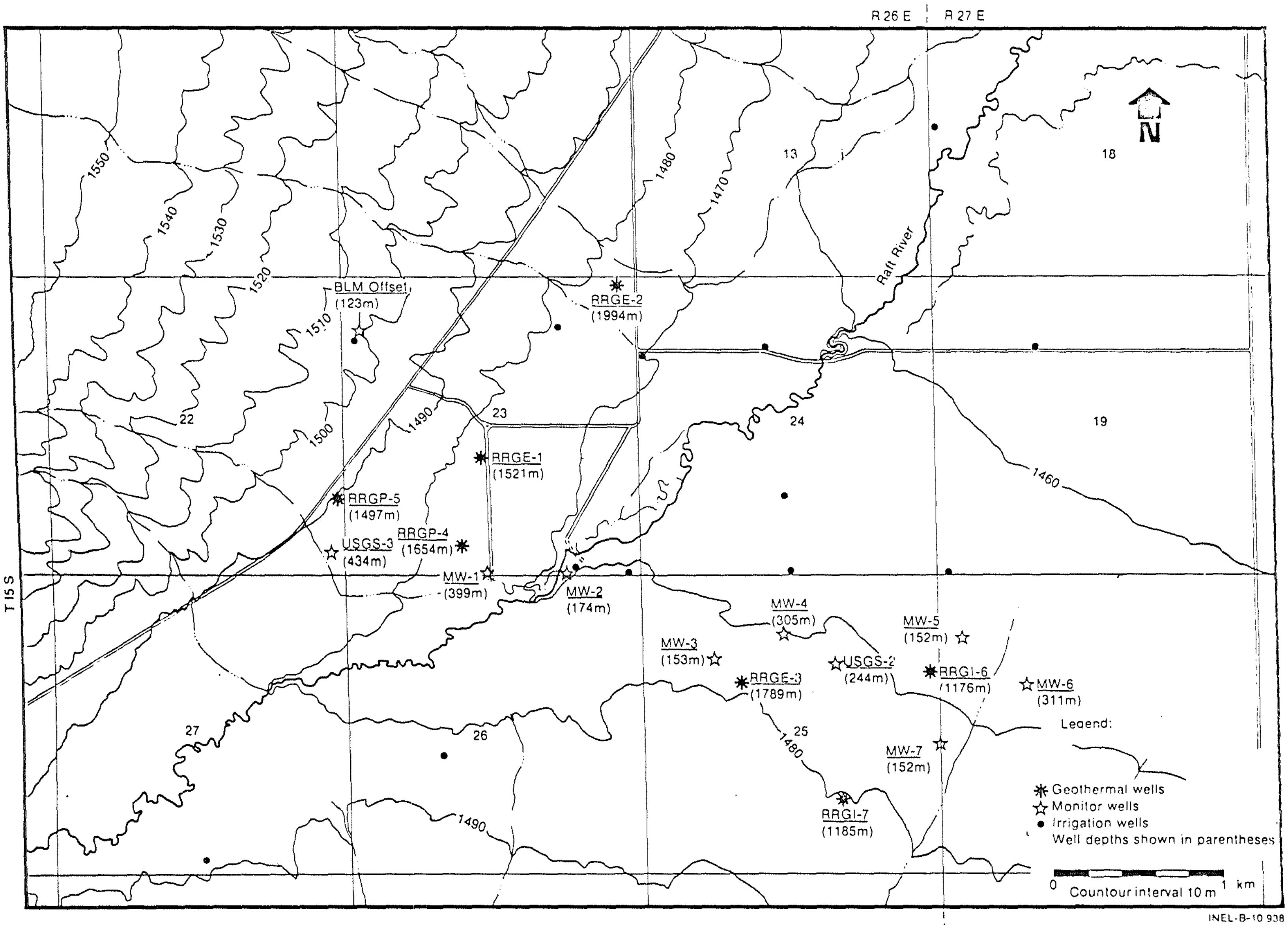
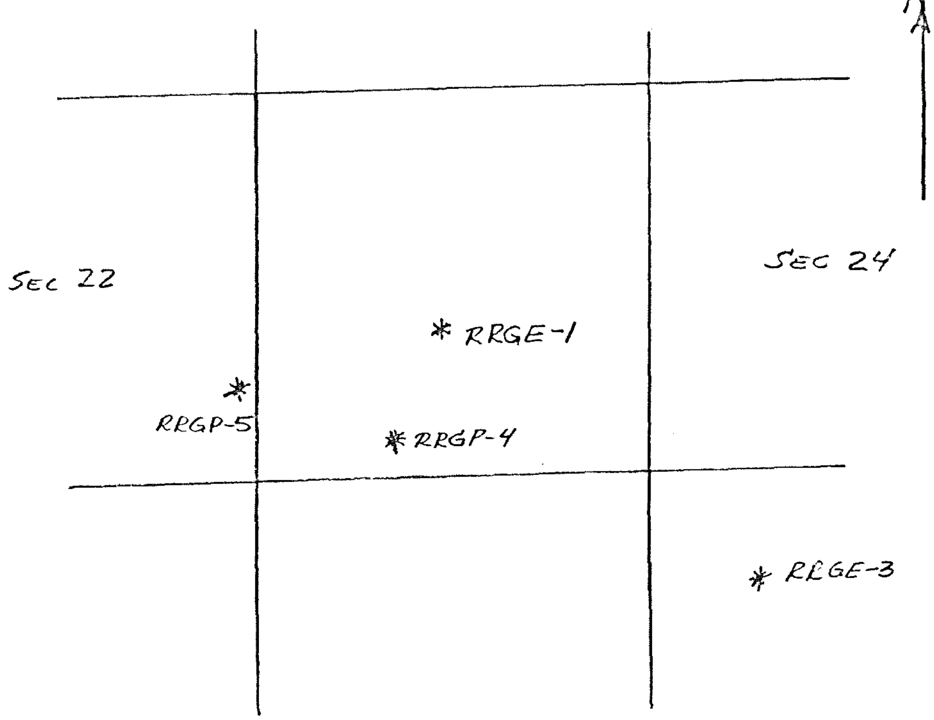


Figure 4. Raft River well field locations.



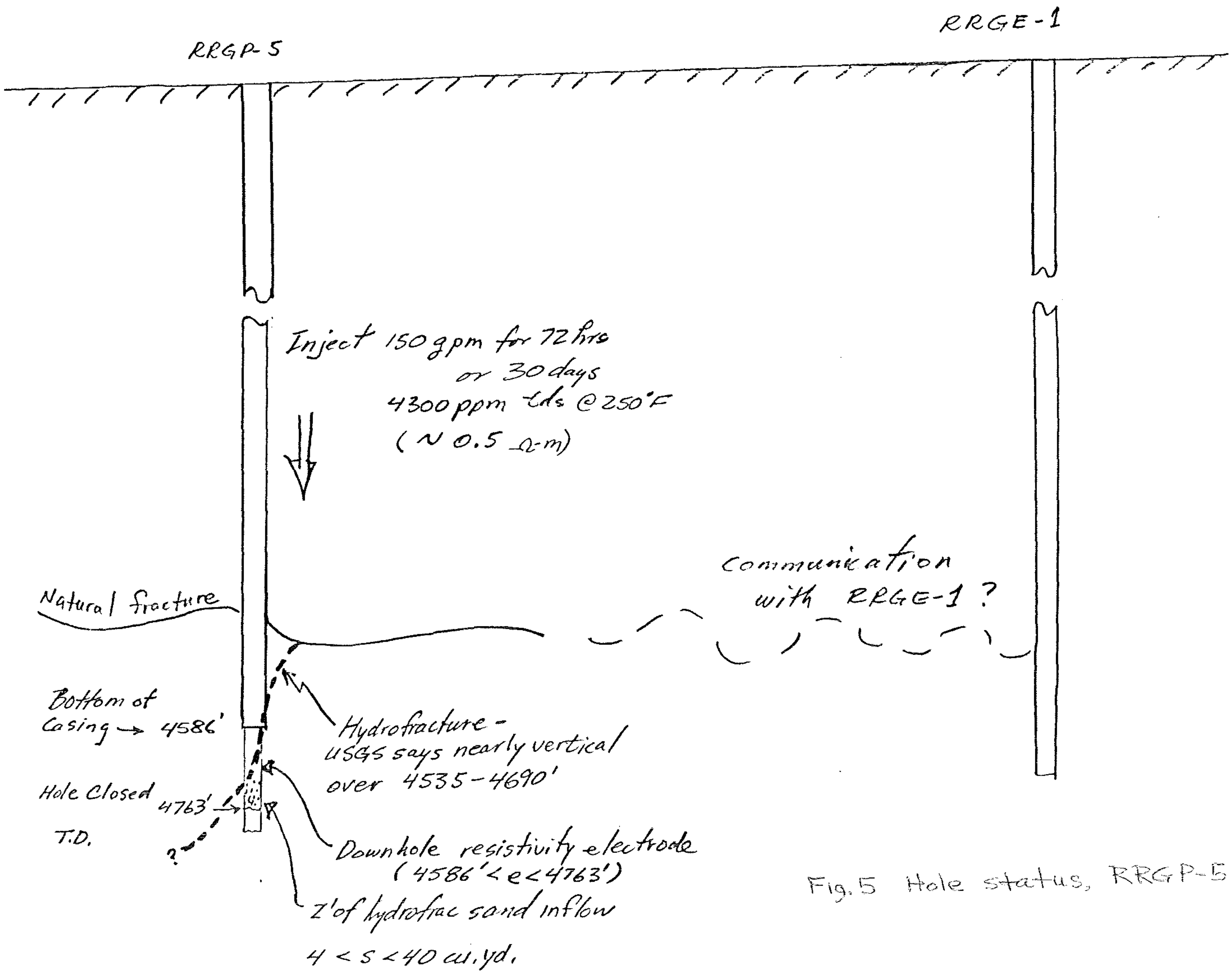


Fig. 5 Hole status, RRGP-5

BLACKETT → HPR.

STRUCTURAL EVOLUTION
OF THE RAFT RIVER BASIN, IDAHO

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CONTENTS

Structural Evolution of the Raft River Basin, Idaho

By H. R. Covington

ABSTRACT

Recent geological mapping, geophysical studies, and deep drilling in the Raft River area, Idaho, have yielded information that is not consistent with fault-block development of the Raft River basin. Paleozoic and lower Mesozoic allochthonous rocks that occur in the surrounding Sublett, Black Pine, Albion, and Raft River Mountains do not occur beneath the Cenozoic basin fill deposits of the Raft River Valley, nor do Cenozoic volcanic rocks that form the adjacent Cotterel and Jim Sage Mountains. Range-front faults have not been identified along the margins of ranges flanking the Raft River Valley. Normal faults found in the Cotterel and Jim Sage Mountains are inferred to be concave-upward extensional structures that involve only Tertiary volcanic rocks and basin-filling sediments. Concave-upward faults within the Raft River basin have been identified in seismic reflection profiles. Fault displacement of the basement rocks beneath the Raft River Valley has not been documented. Structural development of the Raft River basin based on gravity-induced tectonic denudation of nearby metamorphic core complexes is suggested.

INTRODUCTION

The Raft River Valley lies in a north-trending Cenozoic basin near the northern limits of the Basin and Range province. The valley opens northward onto the Snake River Plain and is flanked on the east by the Sublett and Black Pine Mountains; on the west by the Cotterel, Jim Sage, and Albion Mountains; and on the south by the Raft River Mountains (Fig. 1).

Long known as a thermal area (Stearns and others, 1938), part of the southern Raft River Valley, near Bridge, was designated the Frazier Known Geothermal Resource Area (Godwin and others, 1971) by the U.S. Geological Survey in 1971. In 1973, the U.S. Geological Survey and the U.S. Department of Energy (formerly the U.S. Energy Research and Development Administration) began a cooperative multidisciplinary investigation of the Raft River geothermal system in order to provide a scientific framework for the evaluation of a geothermal resource. These investigations included surface geological and geophysical studies and a drilling program designed to aid subsurface studies as well as to develop the geothermal resource. The results of these studies have been summarized by Williams and others (1976), Mabey and others (1978), Keys and Sullivan (1979), and Covington (1980).

The geothermal resource is contained in a fracture-dominated reservoir near the base of the Cenozoic basin fill. Recognition of an extensive fracture system within the basin fill beneath the Raft River Valley requires a different structural model for development of the basin than the fault-block model originally proposed by Williams and others (1976). Recent geological mapping, geophysical studies, and deep drilling in the Raft River area have yielded information that suggests a model based on gravity-induced tectonic denudation of nearby metamorphic core complexes for development of the Raft River basin.

This paper presents evidence for such a model, and describes the sequence of tectonic events in late Cenozoic time.

GEOLOGIC FRAMEWORK

Albion and Raft River Mountains

The Precambrian basement complex that underlies the Raft River area is exposed in five domes within the Albion and Raft River Mountains. The cores of these domes consist of 2.5-b.y.-old (Armstrong, 1976; Compton and others, 1977) Archean granite and granite gneiss unconformably overlain by Proterozoic Z and lower Paleozoic schists and quartzites of the regional autochthon. Above the autochthon, two allochthonous sheets are exposed in the Raft River Mountains (Compton, 1972, 1975; Compton and others, 1977) and possibly as many as four allochthonous sheets are exposed in the Albion Mountains (Armstrong, 1968; Miller, 1980). The lower allochthonous sheets generally consist of metamorphosed lower Paleozoic rocks whereas the upper or highest sheet is slightly metamorphosed or nonmetamorphosed upper Paleozoic and lower Mesozoic rocks. Exposures of the allochthonous sheets are restricted almost wholly to the west flank of the Albion Mountains (Armstrong, 1968; Miller, 1980) and the west end of the Raft River Mountains (Compton, 1972, 1975). An exception is a group of small klippen of nonmetamorphosed upper Paleozoic rocks of the upper allochthonous sheet located along the north and east flanks of the Raft River Mountains (Compton, 1975; Compton and others, 1977). Rock exposures on the east flank of the Albion Mountains and the north flank of the eastern Raft River Mountains are dominantly those of the autochthon (Armstrong, 1968; Compton, 1972, 1975; Miller, 1980). The unconformity between the crystalline basement and the overlying metasedimentary rocks culminates at 2,900 m above sea level in both the Albion (Armstrong, and others, 1978) and Raft River

Mountains (Compton, 1975). Deep drilling in the Raft River Valley has identified the same unconformity at about 300 m below sea level (Covington, 1977a-d, 1979a,b). These elevations yield a minimum structural relief of about 3,200 m, and an average slope of about 6.5 degrees for the top of the Archean crystalline basement. Miller (1980) records slopes in excess of 30 degrees on the flanks of the Big Bertha dome, central Albion Mountains. Normal faults are common in the Albion and Raft River Mountains, but most have small displacements and are not of major structural importance (Armstrong, 1968; Compton and others, 1977; Miller, 1980).

Despite numerous radiometric dates throughout the region, timing of events in the Albion and Raft River Mountains is still open to question. It is generally agreed, however, that: (1) the crystalline basement is 2.5 b.y. old; (2) regional west to east thrusting occurred during the early Tertiary; (3) an early metamorphic event ended in late Cretaceous or early Tertiary time; and (4) a late metamorphic event was active until Miocene time.

Sublett and Black Pine Mountains

Weakly metamorphosed to unmetamorphosed allochthonous miogeoclinal rocks of late Paleozoic to early Mesozoic age make up the Sublett and Black Pine Mountains. These rocks are exposed in two or possibly three structural plates in the Sublett Mountains (R. L. Armstrong, unpub. data, 1977), two structural plates in the northern Black Pine Mountains and three structural plates in the southern Black Pine Mountains (Smith, in press). A high-angle reverse fault, the West Dry Canyon fault (Fig. 2), transects the Black Pine Mountains near West Dry Canyon, separating the mountain range into two distinct structural and lithologic blocks (Smith, in press). Conodont collections from north and south of the West Dry Canyon fault (Fig. 2) indicate that the two structural blocks that form the Black Pine Mountains may have had different thermal histories (Smith, in press). This fault is in close alignment with the Narrows structure (Figs. 1 and 2). Ash-flow tuffs and tuffaceous sediments of Tertiary age exposed along the margins of the two mountain ranges clearly are unconformable on the upper Paleozoic rocks, and locally they contain random bedding dips in excess of 30 degrees (R. L. Armstrong, unpub. data, 1977; Smith in press). Normal faults found within the two mountain ranges are sparse and appear to be of small displacement. Steep gravity contours along the west sides of both mountain ranges (Mabey and Wilson, 1973; Mabey and others, 1978) have been interpreted as faults buried beneath the basin fill on the west side of both ranges. A seismic reflection profile, near the Black Pine Mountains, in the Raft River Valley (Figs. 2, 3B and 4B) shows the basin floor slopes westward away from the range. Rotation of the basin floor appears to be associated with displacement on normal faults that dip eastward toward the mountains.

Cotterel and Jim Sage Mountains

Two Tertiary rhyolite lava flows with a tuffaceous sedimentary unit between them in most places make up the Cotterel and Jim Sage Mountains. Locally the middle sedimentary unit contains vitrophyre breccia and densely welded ash-flow tuff (Williams and others, 1974). The two mountain ranges define a north-trending anticline broken by numerous normal faults. The east flank of the anticline dips 15-35 degrees toward the east, or Raft River basin, and the west flank dips 5-30 degrees toward the west. Most of the normal faults strike between N. 30° E. to N. 30° W., although there are also several faults that strike west-northwest to west (Williams and others, 1974; Pierce and others, in press). The sense of displacement on most of the north-trending faults is down to the east; however along the crests of both ranges apical grabens occur in some places. Displacement on the faults is generally a few meters to a few tens of meters. The greatest offset is on the east side of the Cotterel Mountains, just north of Cassia Creek, where stratigraphic displacement is several hundred meters (Williams and others, in press). North-trending stratigraphic and structural relationships exposed in the Cotterel and Jim Sage Mountains are offset along the valley of Cassia Creek that separates the two ranges. The relationship suggests a right-lateral fault along Cassia Creek, here named the Cassia Creek structure (Figs. 1 and 2). Similarly, stratigraphic and structural relationships across the Raft River Narrows at the south end of the Jim Sage Mountains suggests right-lateral offset on the Narrows structure (Williams and thers, 1976) (Figs. 1 and 2).

Rhyolite lava flows adjacent to the Raft River basin are restricted to the Cotterel and Jim Sage Mountains. The aerial extent of the lava flows is only slightly larger than that of the rock exposures: the flows do not extend far beneath the alluvial fan deposits. Radiometric ages from the upper rhyolite lava indicate that the flows are 9-11 m.y. old (Armstrong, 1976; Williams and others, 1976; Pierce and others, in press). Several small rhyolitic domes along the east flanks of the two mountain ranges and in the southeast corner of the Raft River Valley yield radiometric ages of 7-9 m.y. (Williams and others, 1976). An ash-flow tuff exposed on the east side of the Jim Sage Mountains also yields a radiometric age between 7-9 m.y. (Williams and others, 1976), as does an ash-flow tuff exposed in the upper Raft River Valley southwest of the Jim Sage Mountains (G. B. Dalrymple, written commun., 1979).

Raft River Valley

The Raft River Valley is a north-trending basin filled with nearly 1,600 m of Cenozoic fluvial sediments that began accumulating during the early Miocene. Deep drill-hole data (Covington, 1977 a-d, 1978, 1979a,b; Oriel and others, 1978) indicate a general decrease in gravel content and an increase in open fractures and hydrothermal alteration downward. The drill-hole data also indicate that basin fill south of the Narrows structure is coarser and less well indurated than is basin fill north of the structure. Correlation of depositional units within the basin fill is complicated by rapid lateral changes in both thickness and facies, by hydrothermal alteration, and by complex structures. Seismic refraction studies show that velocities in the basin fill vary laterally and possibly vertically, corresponding to zones of hydrothermal alteration (Ackerman, 1979). Seismic reflection profiles indicate a complex depositional history for the basin (Figs. 3 and 4). Reflectors in the west and east parts of the basin dip basinward, whereas near the center of the basin reflectors are subhorizontal in the shallow part and gently dipping in the deeper part. Lateral discontinuities and terminations of reflectors indicate common faultin_ within the basin fill. 3

Deep drilling in the basin did not reveal lavas of the type exposed in the Cotterel and Jim Sage Mountains, nor were ash-flow tuffs or Paleozoic rocks of the types exposed in the other surrounding mountains found (Covington, 1977a-d, 1978, 1979a,b; Oriel and others, 1978). The base of the Cenozoic fill, marked by a breccia (Covington, 1979b), is in fault contact with schist and quartzite units of the autochthon that can be correlated with formations exposed in the Albion and Raft River Mountains (Covington, 1980). Seismic reflections (Figs. 3 and 4) known or inferred to represent basin-fill sediments dip into subjacent reflections interpreted to be representative of basement rocks.

Quaternary alluvial fans in the southern part of the valley are marked by linear features that were first interpreted to be fault scarps by Williams and others (1974). An east-west set of scarps in the southeast part of the valley, near Naf, probably indicate faulting with the north or basin side down. North-northeast trending scarps on the west side of the valley form two subparallel sets called the Horse Well and Bridge zones (Figs. 1 and 2). Mapping near the Raft River and seismic reflection profiles indicate that the Horse Well and Bridge zones are probably faults with the east or basin side down. Trenching across the zones shows no offset of Quaternary fan material, and small displacements of the Tertiary beds (Williams and others, in press). Gravity contours indicate that the Horse Well and Bridge zones terminate near the Narrows structure (Mabey and others, 1978). A seismic refraction line across the Bridge zone shows no positive evidence of offset on the basement horizon (Ackerman, 1979). Seismic reflection profiles in the area of the Bridge zone show abundant east- and west-dipping faults in the Tertiary basin fill, but no offset in the basement surface (Fig. 3). The faults seen in the reflection profiles are generally steep dipping near the top of the basin fill and flatten downward, becoming subparallel with the top of the basement complex (Fig. 4). Age of last movement on these faults is probably late Pliocene, based on age relations of Quaternary deposits and soils in the northern part of the valley and trenching (Pierce and others, in press; Williams and others, in press). The Cassia Creek structure and the Narrows structure transecting the Raft River Valley in east-west and east-northeast directions, respectively, have no surface expression in the Quaternary alluvium.

Cassia Creek and Narrows Structures

Geologic relations and geophysical anomalies in the Raft River basin indicate the existence of steep east- and east-northeast trending transcurrent structures. The Cassia Creek structure offsets the alignment of stratigraphic and structural relationships between the Jim Sage and Cotterel Mountains along the valley of Cassia Creek (Figs. 1 and 2). Mapping shows a major component of right-lateral movement, and dip-slip with the north side down 200 m.

The Narrows structure passes through the lower Narrows of the Raft River at the south end of the Jim Sage Mountains and across the southern Raft River Valley toward the north end of the Black Pine Mountains (Figs. 1 and 2). On opposite sides of the Raft River Narrows, discordant relations in Tertiary sediments and rhyolite lavas indicate right-lateral offset on the Narrows structure. Within the southern Raft River Valley there is no direct geological expression of the Narrows structure. It was noted above that none of the north-trending normal faults in the Jim Sage Mountains or Raft River Valley cross the Narrows structure (Williams and others, 1976) and that the nature of the Tertiary basin fill is somewhat different on either side of the structure. Geophysical studies in the form of gravity, magnetic, seismic refraction, and d-c resistivity surveys indicate north-east trending anomalies in the Tertiary rocks east of the Raft River Narrows (Mabey and others, 1978). The data indicate the existence of major geologic changes across the zone, but they do not define a discrete structure. Seismic refraction studies (Ackerman, 1979) and seismic reflection profiles show extreme complexity of the Tertiary basin fill, but do not indicate the presence of a basement feature that might coincide with the Narrows structure. Deep drilling within the zone of the Narrows structure also shows chaotic basin fill with no apparent disturbance of the basement rocks.

DISCUSSION

Structurally, the gneiss domes that form the "cores" of the Albion and Raft River Mountains are prominent features in the area. Prior to gneiss dome development, regional west-to-east overthrusting placed thick sheets of Paleozoic and lower Mesozoic rock over the entire area. Presently these allochthonous sheets primarily occur on the west side of the Albion Mountains, the west end of the Raft River Mountains and in the Sublett and Black Pine Mountains. Only small patches or "klippen" are found on the east flank of the Albion Mountains and along the north and east flanks of the Raft River Mountains. No Paleozoic or lower Mesozoic rocks have been identified within the Raft River basin from deep drilling in the basin. Seismic reflection profiles indicate that Paleozoic rocks may exist beneath basin fill along the east margins of the valley near the Sublett and Black Pine Mountains, where no drill-hole data are available (Figs. 3 and 4). In order to explain these relationships by block faulting, at least 5,000 m of Paleozoic and lower Mesozoic rock needs to be removed from the Raft River basin area during an episode of pre-basin block uplift and erosion. There is no known sedimentary record of this event nor have the required faults been identified.

The rhyolitic lavas that form the Cotterel and Jim Sage Mountains are highly restricted in their east-west distribution and yet extend 55 km in a north-south direction. Drilling in the Raft River Valley has not identified these rocks within the sedimentary basin fill, nor have ash-flow tuffs found on the flanks of the surrounding mountains been identified within the Raft River basin fill. The absence of these volcanic rocks within the Raft River basin fill also is inconsistent with a block-fault model, because the basin areas where these rocks are missing would have to have been a positive topographic and structural feature during volcanism. Tectonic denudation of the nearby gneiss domes presents a much simpler explanation for the distribution of Paleozoic, lower Mesozoic, and Tertiary volcanic rocks in the Raft River area.

High-angle normal faulting within the Albion, Raft River, Sublett, and Black Pine Mountains played a minor role and no large displacements have been observed. Range-front faults have not been mapped on the west side of the Sublett or Black Pine Mountains. A seismic reflection profile in the eastern part of the Raft River basin suggests an eastward-thinning wedge of basin-fill sediments. Lateral terminations and discontinuities in reflections are interpreted as faults that displace strata down toward the Black Pine Mountains (Figs. 3B and 4B). If the faults are low-angle extensional structures dipping eastward toward the mountains (Fig. 4B), a tectonic denudation model easily explains the observed features. Normal faults are abundant in the Jim Sage and Cotterel Mountains and were inferred along the west side of the southern Raft River Valley. Faults along the west margin of the valley were first thought by Williams and others (1974) to be buried range-front faults based on displacement toward the basin and a steep gravity profile. Seismic reflections (Fig. 3), seismic refraction, and drilling in the basin could not confirm basement displacement along the east side of the Jim Sage Mountains. The seismic reflection profiles indicate concave-upward extensional structures near the west side of the Raft River basin that involve only the Tertiary basin fill (Figs. 3A and 4A). Deep drilling within the basin has identified a breccia zone throughout the southern Raft River basin at the Tertiary-Precambrian contact. These structural features support the tectonic denudation model for basin development.

The Cassia Creek structure appears to be a near-vertical detachment surface analogous with a tear fault within the Cenozoic rocks that has allowed differential translation of the Cotterel and Jim Sage Mountains (Figs. 1 and 2). The Narrows structure is also a near-vertical detachment surface within the Cenozoic rocks that has allowed some differential translation at the southern end of the Jim Sage Mountains (Figs. 1 and 2). The West Dry Canyon fault (Fig. 2), separating the northern and southern Black Pine Mountain blocks, is apparently an extension of the Narrows structure. Geological and structural features found in the surrounding mountains and within the Raft River basin, described above, can be explained best by using a model based on gravity-induced tectonic denudation of the nearby gneiss dome complexes.

INTERPRETATION

The sequence of late Cenozoic tectonic events related to uplift of the metamorphic core complexes and subsequent tectonic denudation is shown in an interpretative mode in Figures 5A-E.

Extensive subhorizontal allochthonous sheets of Paleozoic and lower Mesozoic rocks totaling more than 10,000 m in thickness were in place over the entire region by middle Oligocene time as inferred from Armstrong (1968) and Compton and others (1977). In the late Oligocene, a regional increase in thermal activity produced plutons at depth and initiated regional metamorphism, and the development of gneiss domes beneath the present Albion and Raft River Mountains. As the domes rose, metamorphic fluids produced by the increase in regional thermal activity increased the fluid pore pressure near the base of the Paleozoic and lower Mesozoic cover rocks. At some point early in dome development, fluid pore pressure exceeded lithostatic load and a detachment surface formed along a previous thrust surface at the top of the autochthon (Fig. 5A). Gravity-induced gliding of the entire overlying section of allochthonous Paleozoic and lower Mesozoic cover rocks began in a generally eastward direction away from the domes, in a manner similar to that described by Davis and Coney (1979). As a result of sustained high fluid pore pressure and a rapid rate of dome uplift, the allochthonous cover rocks moved away from the domes as large coherent blocks (Figs. 5A, B, C) rather than as thin slices extending along low-angle extensional faults. Clastic sediments were deposited on the flanks of the domes in the wake of these relatively high-standing gravity-glide blocks (Fig. 5B). By the late Miocene, the trailing edge of the gravity-glide blocks had moved about 25 km eastward from their original position above the gneiss domes. Coinciding with the northeastward passage of the thermal pulse now beneath Yellowstone National Park

(Christiansen and Lipman, 1972), rhyolitic lavas and associated ash-flow tuffs and tuffaceous sediments of the Jim Sage Volcanic Member of the Salt Lake Formation (Williams and others, in press) were deposited in this narrow basin (Fig. 5C).

The basin-fill sediments and volcanic rocks moved eastward along the detachment surface with the Paleozoic and lower Mesozoic cover rock for 1-3 m.y. Between 9 and 7 m.y. ago, the volcanic rocks and locally associated sediments ceased to move eastward along the detachment surface; this may have been the result of local sagging in the basement surface, irregularities in the detachment surface due to earlier regional sagging of the basement surface, or a reduction in fluid pore pressure, or a combination of factors. The Narrows and the Cassia Creek structures developed as transverse faults to compensate for contrasting distance and rate of movement to the east.

During late Miocene time, ash-flow tuffs were deposited across the existing valleys and onto the flanks of the existing mountains. Meanwhile, voluminous sediments were being deposited into the expanding basin between the eastward-moving gravity-glide blocks and the rising gneiss domes. Sagging of parts of the basement surface near the domes began as thermal activity decreased. This sagging caused the broken anticlinal shape of the Jim Sage and Cotterel Mountains and created a deep sediment trap between the eastward-moving gravity-glide blocks and the domes (Fig. 5D). With continued rising of the basement rocks and eastward movement of the large coherent blocks of Paleozoic and lower Mesozoic rock, extension of the basin-filling sediments and volcanic rocks along concave-upward normal faults was initiated (Fig. 5D). The concave-upward faults have steep dips (60^{o}-90^{o}) at the surface flattening downward until the faults merge with the detachment surface at the base of the Cenozoic basin fill. These extensional faults are interpreted as growth-type faults in which displacement increases in progressively older strata. Merging of the faults downward into a single zone results in large displacements along the basin fill-basement detachment surface. By the Pliocene, mechanics of the gravity-glide detachment surface had changed sufficiently to bring about extension of the eastward-moving Paleozoic and lower Mesozoic rocks along low-angle extensional faults (Fig. 5D). Extension of the Raft River basin cover terrain, including both the Paleozoic and lower Mesozoic rocks and the basin-filling sediments and volcanic rocks, continued through the Pliocene (Williams and others, in press) and still may be active (Fig. 5E).

ACKNOWLEDGMENTS

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EXPLANATION OF MAP SYMBOLS

Qs	QUATERNARY SEDIMENTS
Ts	TERTIARY SEDIMENTS
Tv	TERTIARY ASH-FLOW TUFFS
Tvd	TERTIARY DOMES--Shallow intrusive rocks of rhyolitic composition
Tvl	TERTIARY LAVA FLOWS--Rhyolitic lava flows of the Jim Sage and Cotterel Mountains
Tg	TERTIARY GRANITE
PzZs	PALEOZOIC AND PROTEROZOIC Z SEDIMENTARY AND METASEDIMENTARY ROCKS OF THE ALLOCHTHON
PzZm	LOWER PALEOZOIC AND PROTEROZOIC Z METASEDIMENTARY ROCKS OF THE AUTOCHTHON
Ag	ARCHEAN GRANITE--Massive and gneissic
mr	METAMORPHIC ROCKS OF UNKNOWN AGE AND CORRELATION
	CONTACT
	NORMAL FAULT--Dotted where inferred, bar and ball on downthrown side
	THRUST FAULT--Teeth on upper plate
⊙	BOREHOLE LOCATION

Figure 1.--INDEX MAP, showing area of geologic map (Fig. 2) and major inferred structures. Bar and ball on downthrown side of faults, arrow indicates direction of slip.

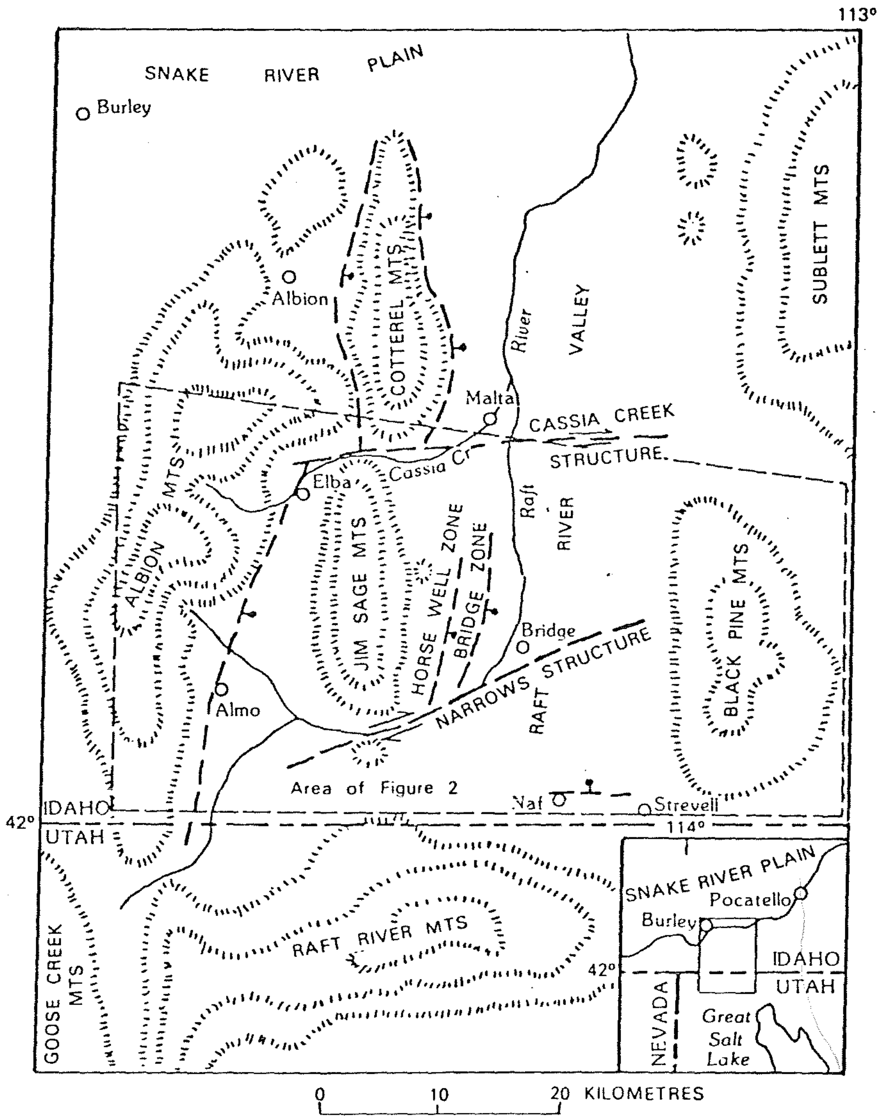
Figure 2.--GENERALIZED GEOLOGIC MAP OF THE SOUTHERN RAFT RIVER VALLEY, IDAHO, showing locations of boreholes, seismic reflection profiles (Figs. 3 and 4), and line of interpretative structure section (Fig. 5E).

Figure 3.--Seismic reflection profile (migrated), west (A) to east (B), across the southern Raft River Valley, Idaho.

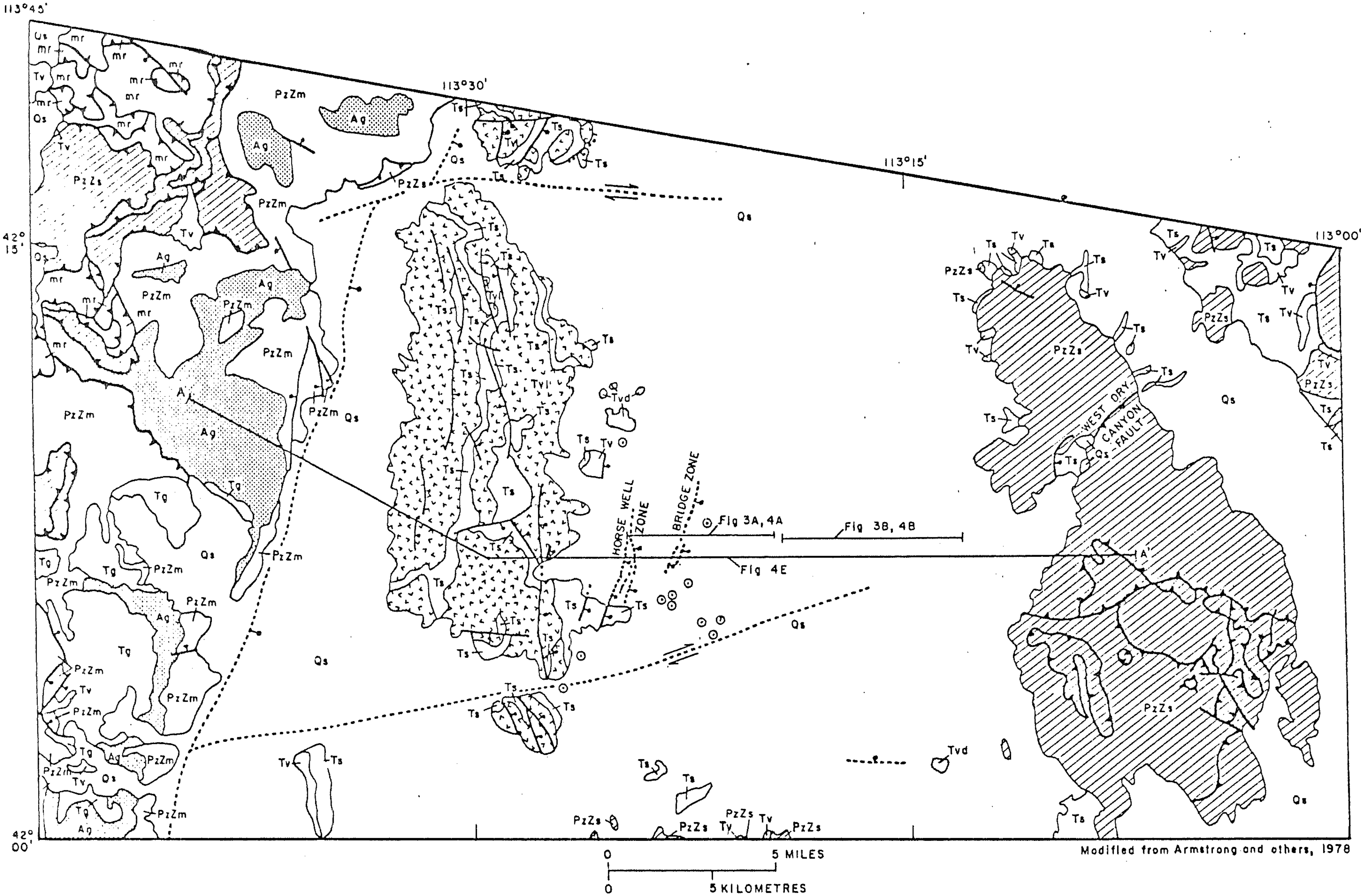
Figure 4.--Interpretative seismic reflection profiles (migrated), west (A) to east (B) across the southern Raft River Valley, Idaho. A, Cenozoic basin fill; B, detachment surface; C, ductilly deformed lower Paleozoic and Proterozoic Z schists and quartzites; D, metamorphosed to nonmetamorphosed Paleozoic and Proterozoic Z rocks; and E, Archean granitic basement rocks.

Figure 5.--Time-sequential, schematic structure sections across the southern Raft River basin, Idaho, showing interpreted stages of basin evolution. A, Metamorphism and expansion of basement rocks, ductile thinning of schists and quartzites of the autochthon, formation of a detachment surface and beginning of gravity-gliding of cover rocks away from rising dome; B, continued thermal expansion of basement rocks and gravity-gliding of cover rocks away from dome, deposition of clastic sediments on flank of domes; C, eruption of rhyolitic lavas in restricted basin between rising domes and eastward moving gravity-glide blocks; D, sagging of basement complex near domes, extension of basin filling sediments and

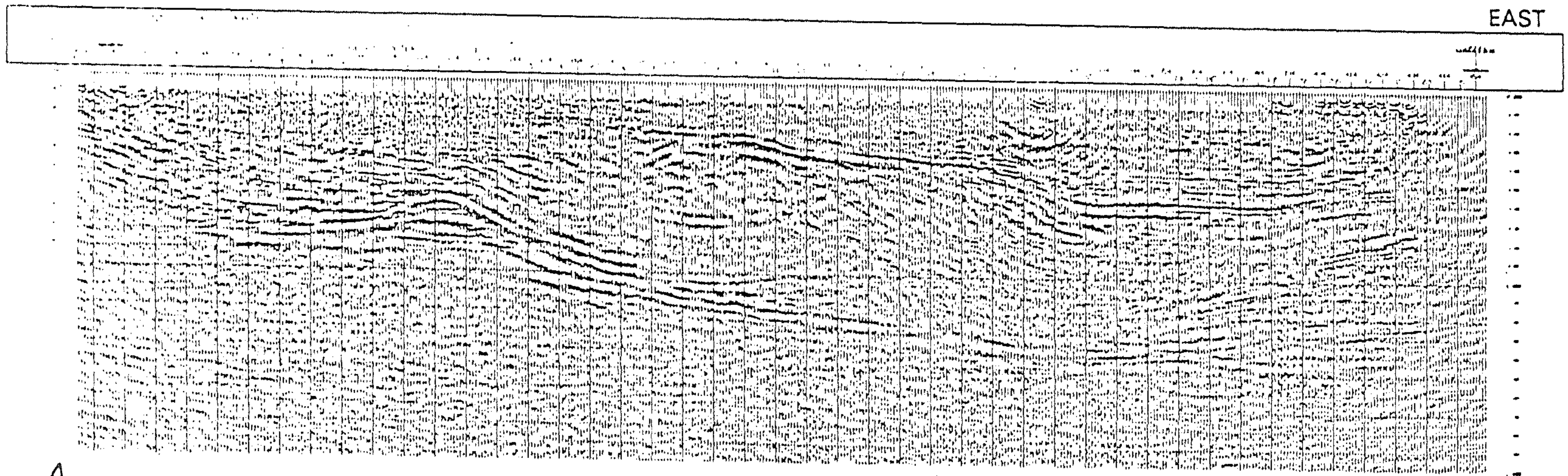
volcanic rocks and Paleozoic-Proterozoic Z glide blocks along concave-upward normal faults; and E, interpretative structure section (A-A', Fig. 2) from Cache Peak in the Albion Mountains to Black Pine Peak in the Black Pine Mountains. Paleozoic and Proterozoic Z rocks are unit D in Figure 4B.



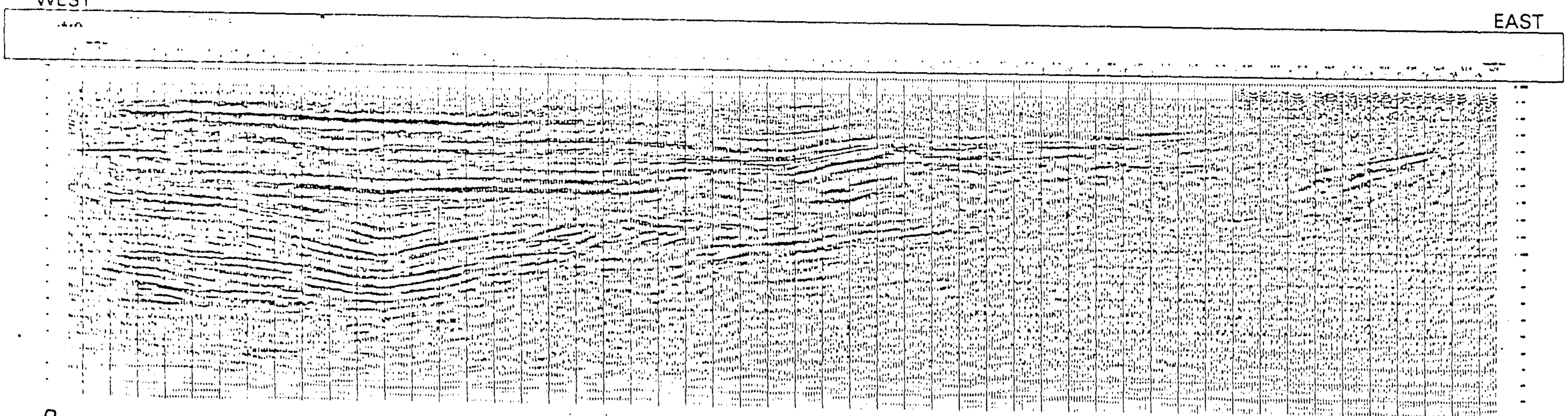
113°
SNAKE RIVER PLAIN
Burley
Albion
COTTEREL MTS
River
VALLEY
SUBLETT MTS
Malta
CASSIA CREEK
STRUCTURE
ALBION MTS
Elba
Cassia Cr
Raft
RIVER
JIM SAGE MTS
HORSE WELL ZONE
BRIDGE ZONE
Bridge
NARROWS STRUCTURE
RAFT
BLACK PINE MTS
Almo
Area of Figure 2
Naf
Strevell
IDAHO
42°
UTAH
114°
GOOSE CREEK MTS
RAFT RIVER MTS
SNAKE RIVER PLAIN
Pocatello
Burley
IDAHO
UTAH
42°
NEVADA
Great Salt Lake
0
10
20 KILOMETRES



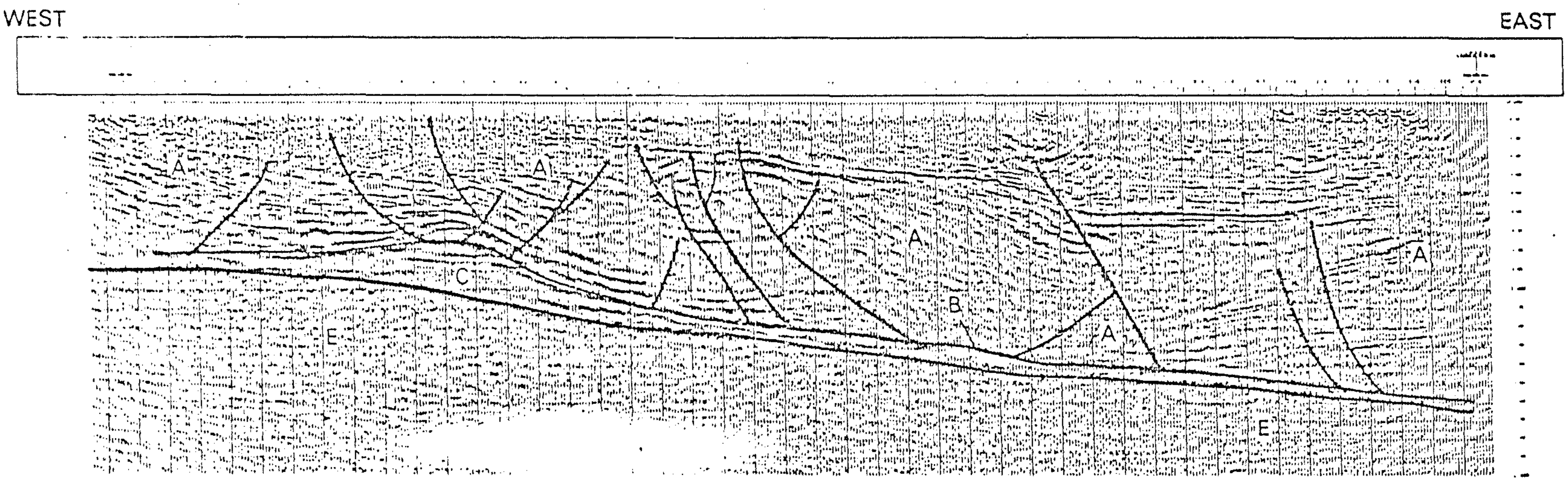
Modified from Armstrong and others, 1978



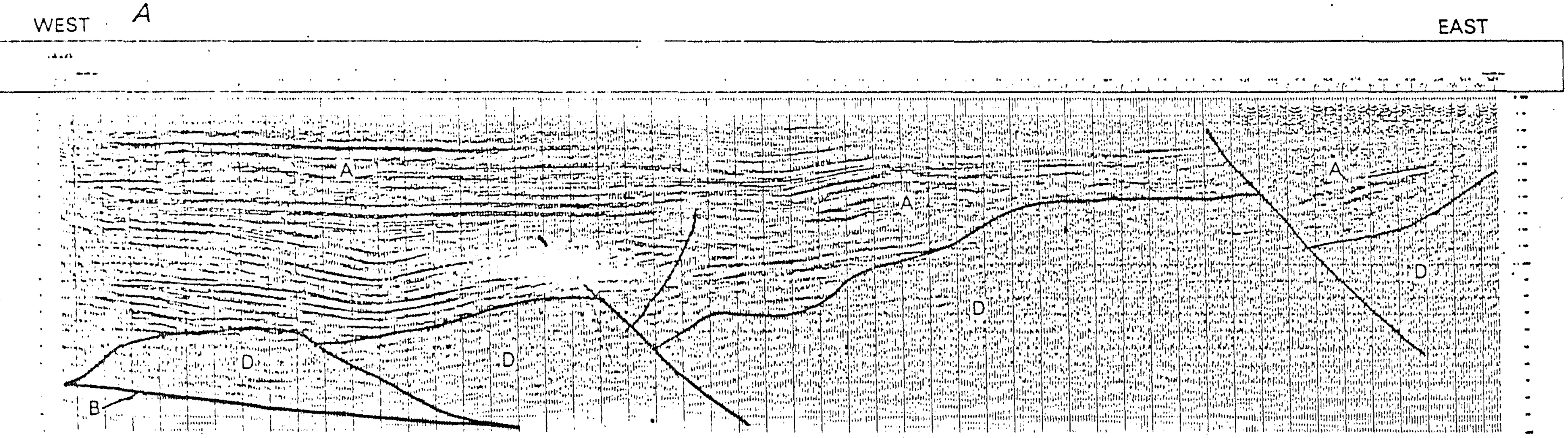
A



B

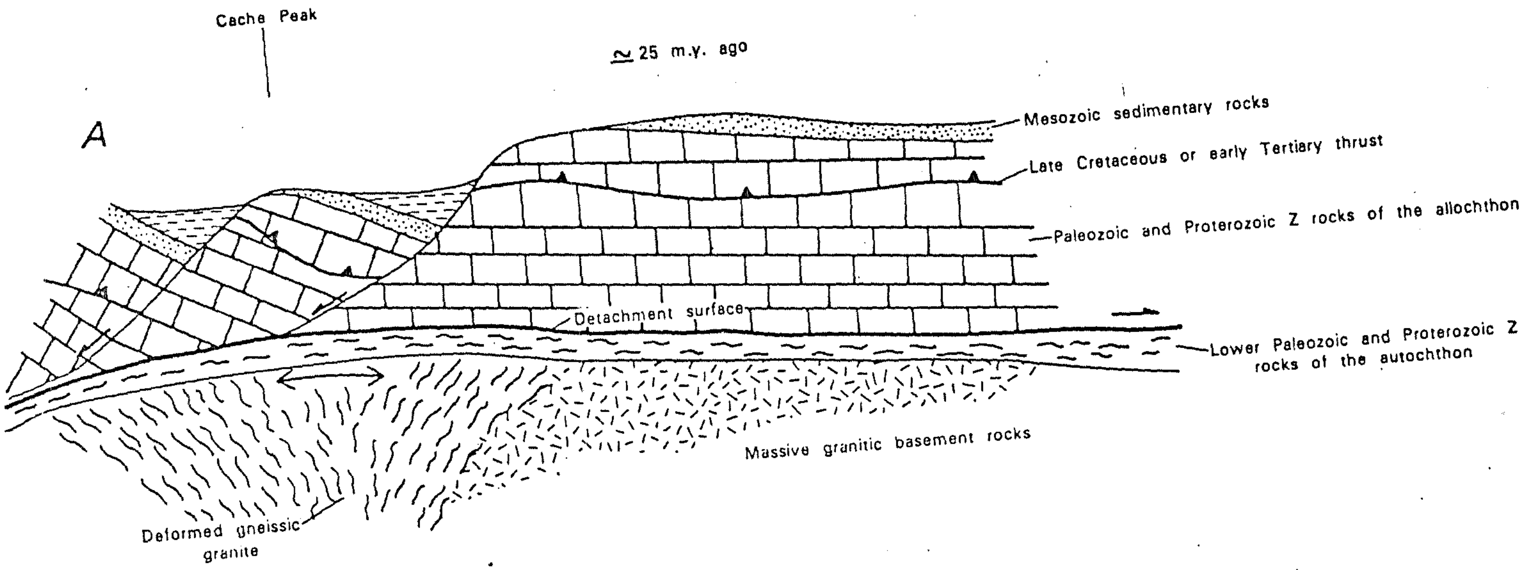


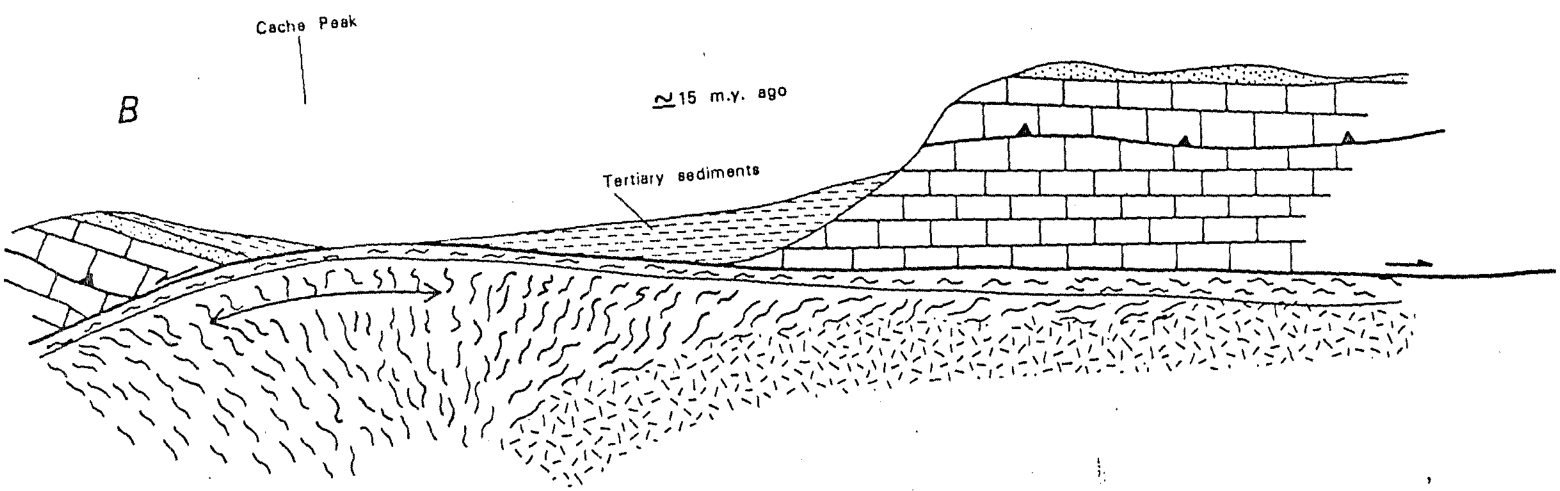
A

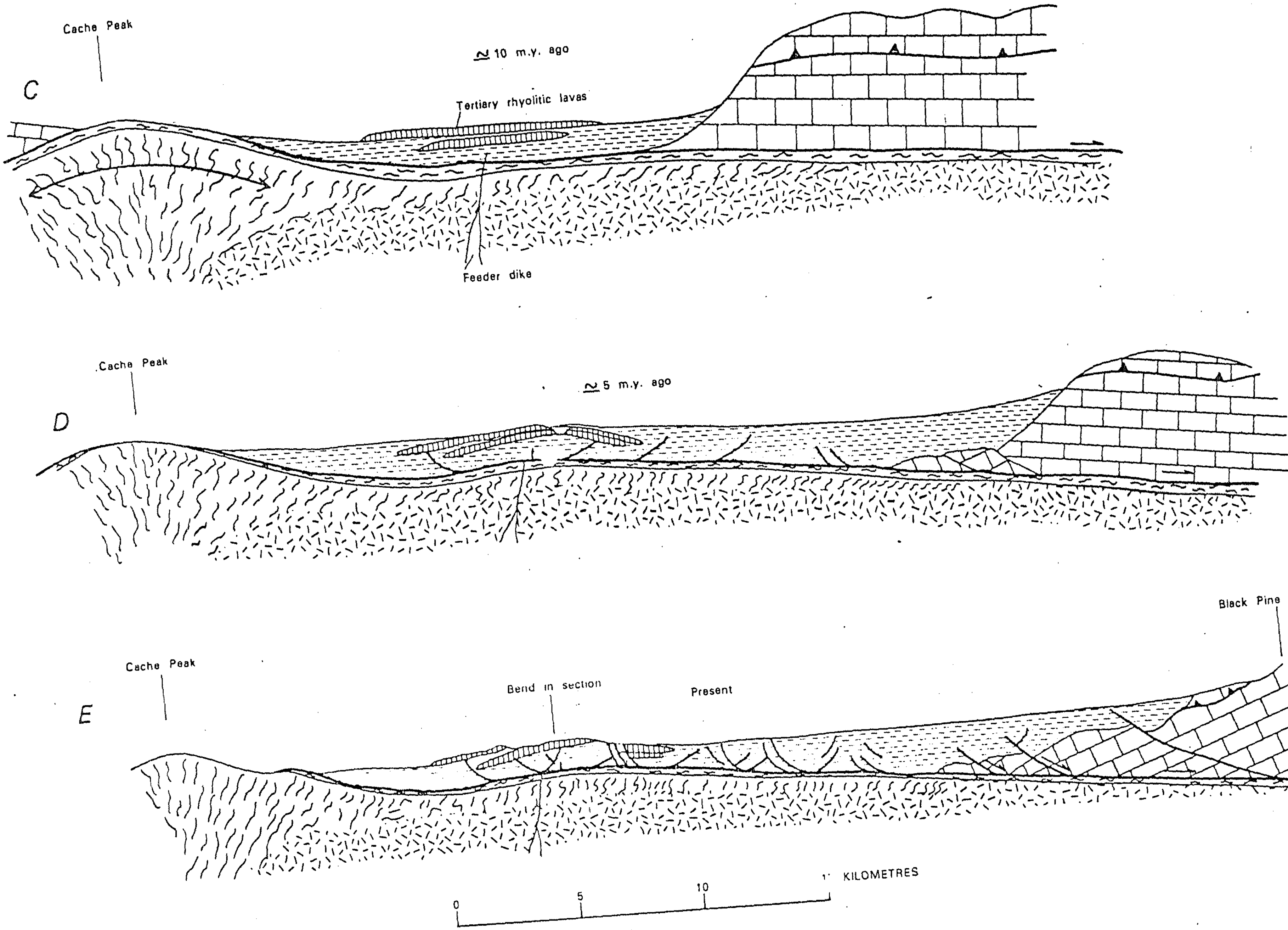


B

A = Cenozoic Basin Fill
B = Detachment surface
C = Lower Paleozoic & Proterozoic Z schists & qtzite
D = Meta tonor Meta C
E = Archean granitic basement


Cache Peak
~25 m.y. ago
A
Mesozoic sedimentary rocks
Late Cretaceous or early Tertiary thrust
Paleozoic and Proterozoic Z rocks of the allochthon
Detachment surface
Lower Paleozoic and Proterozoic Z rocks of the autochthon
Massive granitic basement rocks
Deformed gneissic granite


Cache Peak
B
~15 m.y. ago
Tertiary sediments



Cache Peak
C
≈ 10 m.y. ago
Tertiary rhyolitic lavas
Feeder dike
Cache Peak
D
≈ 5 m.y. ago
Black Pine Peak
Cache Peak
E
Bend in section
Present
KILOMETRES
0
5
10