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BIGHORN- BEARTOOTH REGION

BIG HORN REGION

EROSIONAL HISTORY OF THE BIG HORN BASIN, WYOMING.

J.Hoover Mackin, Bull.GSA 48 (1937)813-894.

Formation of the Basin by Laramide Differential Movements. In late Cretaceous seas that had covered most of W Wyo and Montana withdrew. Thick series continental beds deposited on Great Plains E of the rising Laramide Rocky Mts. Deposition gave way to active fluvial erosion over plains area as a whole during Eocene, but complete sequence of transitional and early Tertiary seds laid down in basins within the mt. front. Fossils and lithology of Big Horn basin seds. show nature of orogenic movements by which basin formed, and general geomorphic aspect of early Tertiary Middle Rocks.

Relative uplift of surrounding ranges, with attendant compression of basin-filling beds was more or less continuous during late Cret., Paleocene, early Eocene; this shown by folding and local unconformities within, and between, the members of the fluvial deposits within the Big Horn Basin. See:

W.J.Sinclair & Walter Granger: Eocene & Oligocene of the Wind River & Big Horn Basins. Am.Mus.Nat.Hist.Bull.vol.30, art.7(1911) p.106.

D.F.Hewett & C.T.Lupton: Anticlines in the southern part of the Big Horn Basin, Wyo. USGS Bull.656 (1917).

W.T.Thom Jr. & C.E.Dobbin: Stratigraphy of Cret-Eocene transition beds in eastern Montana & the Dakotas. Bull.GSA 35 (1924)481-505.

G.L.Jepson: Stratigraphy & paleontology of the Paleocene of northeastern Park Co., Wyo. Am.Philosoph.Soc.Proc.vol.69, No.7(1930)463-528.

At present difference between reexhumed erosion surface at base of Paleozoic sequence near the crests of the ranges and the level of this same granitic surface under the basin may be of the order of magnitude of 27,000 feet. B.Gutenberg, J.P.Buwalda: Seismic methods applied to Bighorn Basin Abstr.GSA Proc.1934(1935) 79-80.

% of this structural relief pre-Middle Eocene movements uncertain, for amount of possible later Tert. vertical movements unknown. Lithology in seds shows ranges greatly raised, enough to strip thick Paleo, Meso cover in Ft.Union, Wasatch times. (pebbles of aleo ls & pre-C granite deposited near basin borders. D.F.Hewett: Geology and oil and coal resources of Oregon Basin etc. quadrangles, Wyo. USGS PP 145(1926), 30-47.

Paleobotany shows basin floor much lower during Eocene than at present. Bridger lignite beds now 6000' elev., probably laid down not over 1000' above sea level. p.819: "These relations support the view that the Laramide orogenic movements in the Middle Rockies were predominantly differential displacements of basins and ranges, absolute uplift of the ranges being accompanied by absolute downwarping of the basin floors."

Present aridity of Wyo basins related to altitude of ranges to W, in path of damp Pacific winds. Faunas and floras of early Tertiary indicate prevailing humidity: ranges of Middle Rockies did not in early Tertiary reach present ht. above sea-level. Granite detritus in early Tert. seds. in Big Horn basin provesenclrcling ranges greatly elevated, deeply erodded, but it does not prove that Laramide differential movements produced high mts. that were peneplaned ~~in~~ during Eocene, for early Tertiary humidity appears to have been a continuation of antecedent Cret. conditions r rather than a renewal of mild climates after a cycle of uplift and erosion. In harmony with the record of continued mild climates during the period of Laramide differential movement is the suggestion that erosion of relatively weak upwarched Mesozoic rocks might have more or less kept pace with uplift of the ranges. Max Bauer bases same theory on dufferent evidence: Wind River Basin, GSA Bull. 45(1934)690-691).

Post-Laramide Regional Uplift.- Bridger Tatman Mt. lignitic shales are youngest early Tertiary beds preserved in Big Horn Basin; but critical climatic change recorded in Wind River Basin & on Great Plains. Sinclair & Granger op. cit. say presence of coarse arkoses and ls. of evaporation in late Eocene and Oligocene beds of Wind River Basin show change from earlier humid conditions in basin floors toward progressively increasing ~~humidity~~ aridity. p.114. R.S. Lull: Evolution of the horse family, as illustrated in the Yale collections. Am. Jnl. Sci. 4th ser. vol. 23 ((1907) p.173. Forests shrank, true prairies developed on Oligocene plains reflected in development of horse. By late Miocene many browsing herbivores of plains extinct; surviving types could grind harsh grasses. Semi-arid regime initiated in Oligocene increased progressively in severity thru mid-Tertiary until in late Mio, Plio, it approximated present Plains climate. This dry climate due to W mt. barrier. p.820: "For this reason, the slow change from early Tertiary humid conditions, indivated by floras and faunas of the basins, to mid-Tertiary semi-arid conditions on the Plains and in intermontane basins, indicated by widespread changesin all forms of life, is interpreted as the direct result of progressive regional uplift of the Rocky Mountains and the western Plains. There is evidence, noted by many writersmthat differential movements of the ranges accompanied regional uplift" See E. Blackwelder: Post-Cret. history of the mountains of central-western Wyoming. JG 23 (1915)112-117.

Eocene streams of Plains were able to transport E the waste that escaped from downsinking intermontane basins, and also to cut deeply into older Plains strata. Other conditions unchanged, regional uplift of mts. and W Plains in Oligocene, Mio., Plio should have quickened erosion by E-flowing streams in middle and late Tert. But deposition, not erosion. in Plains. Opposing factor; tending to offset this direct effect of uplift: automatic steepening of the graded declivities of the Plains streams in response to (1) increasing aridity, loss of water supply and (2) increasing ht. of mts. to W, involving a marked increase in amount and coarseness of load available for transportation e astward.

Altitude of Big Horn Basin Floor at culimination of period of aggradation. Aggradation culminated in late Tertiary in production of a vast E-sloping alluvial surface of which the High Plains is a greatly shrunken erosion remnant. Later erosion esp. active near the mts. has destroyed former W extension of aggraded surface; but it formerly extended W into intermontane basins, these largely filled with detrtitus before start of present cysle of down-cutting. Filled basins to high level.

Extensive deposits of stream-rounded gravel at 7-9000 ft.,flanks of Big Horn range. These slope smoothly outward from hich axial peaks of range but end abruptly in a steep descending scarp at the range front. Projections of this slope across and above the present lowland define the form of the basin floor at the culmination of the period of aggradation.

There is a striking erosion surface at 8000 to 10000 ft.on flanks of the ranges that surround the basin. Generally assigned to Pliocene (Sub-summit peneplain)with inference it was formed at a low level and that its present elevation and the deep trenching of the present streams are due to uplift subsequent to its formation. But if as suggested here the gravel that still mantles part of this erosion surface was formerly continuous with the aggraded floor of the basin and in turn with the late Tertiary aggradationa surface of the Great Plains,very different history. Willard Johnson The High Plains and their utilization,USGS 22nd An.Rept.pt.4,1902,p.638) emphasized a pt.overlooked by later workers:original slope of deposition of High Plains tertiary beds could not have been much less than present E slope of these strata. This is critical,for it means that W margin of Plains,all extensions of the aggraded surface in intermontane basins,and all related erosion surfacesof the mts.could not have been formed near base-level,but must have been formed at a high level determined by the declivities of the streams of the Plains and the distance to the sea.

This means that majorregional uplift of the Rocks occurred during, or before, mid-Tertiary,and this is in harmony with record of climatic change on the Plains to the E,for as pointed out,semi-arid to arid regime of Plains incipient in Late Eocene and Oligo,became marked in Miocene & and has continued to present.

Alternative theory of deep-mid-Tertiary degradation of the mts.and very marked late Tertiary or early Pleistocene uplift is in direct conflict with this clamatic record. There was no middle or late Tertiary peneplanation of Rocks.

Summary (p.824):"The lithologic character and fossil content of the late Cretaceous and earliest Tertiary beds of the Big Horn Basin indicate that the floor of the basin stood at a relatively low level during the period of Laramide differential movement by which the structural basin was largely formed.Regional uplift,beginnin in late Eocene or Oligocene,raised both the encircling ranges and the prism of inwashed early Tertiary seds. to a high level and caused changesin the character of the east-flowing streams,which resulted in widespread aggradation. Dowbcutting in the present cycle may be due, in part, to changes in the graded declivities of the streams flowing to the sea. The present drainage pattern of the basin is inherited,with some modification throuf capture,from the pattern controlled by the slopes of the waste fill."

BEARTOOTH-BIGHORN REGION, MONTANA-WYOMING.

1. C.L.Dake: Episodes in Rocky Mountain Orogeny. Am.Jnl.Sci.5th Ser. vol.1,1921, 245-254.

Three orogenic episodes in NW Wyoming: (1) post-Lance,pre-Fort Union (?);(2) Post-Fort Union(?), pre-Wasatch; (3) thrusting of great blocks of Miss. ls. many miles over Fort Union(?) pebbly ss. Post-Bridges The major thrust plane is notably warped "but this warping may have occurred as the faulting was going on"(page 254). Pre-early Basic Breccia (Neocene). There may have been a pre-Lance epoch-uplift.

2. A.E.Fath: Age of the Domes and Anticlines in the Lost Soldier-Ferris District, Wyo. J.G.30,1922,303-310.

Northernmost member of series of Rocky Mt. flexures. Its trend N-S. Not this Rky Mt. fold's Change abruptly Trend E-W. Sweetwater is one.

Deals with relative age of the major and minor folding. Refers to Max Ball:Relative Ages of Major and Minor Folding and Oil Accumulation in Wyoming. Bull.AAPG 5(1921),49-63. Ball thinks nearly all minor folds of Wyoming formed during the period of formation of major uplifts.(Many exceptions Fath; but agrees in general with Ball's conclusion.)

Rawlins Uplift: SE of Lost Soldier and Wertz domes.A small pre-Cambrian exposure.This uplift was complete by the start of Wasatch time. The pre-Cambrian central core is faulted on the west;toward the N this fault turns NE and crosses the axis of the uplift.That part of the uplift N of this fault has been down-dropped.The oil and gas fields of the Lost Soldier and Ferris district lie in this part of the uplift.The minor folds here form the subject of the paper.

Mesa verde etc. horiz. Tert. Seds form flat plain around granite peaks

Sweetwater Uplift:In SE Fremont Co.,SW Natrona Co.South central Wyo. Trends E-W, 100 x 40 miles.Pre-Cambrian core. The south margin,adjacent to the Lost Soldier-Ferris District, comprises the Ferris and Seminole Mountains,the Ferris on the W,the Seminoles on the E.The north side of the Ferris Mts. consists of pre-Cambrian crystallines,adjacent to which and sharply upturned are Paleozoinc-Mesozoic sediments that form the S side of the Ferris Mts. These sediments are in places vertical to overturned, high on the mt. flanks.

SE of the Ferris Mts. this sharp folding is replaced by thrusting from the north,so that the crystalline rocks of the Seminole Mts. now lie against the Cretaceous rocks of the Lost Soldier district.The minor fault plane is vertical,and the horizontal displacement is therefore slight.But the sediments are somewhat overturned. The Sweetwater uplift is mainly pre-Wasatch.It differs from the Rawlins uplift in that the main deformation was followed by sizable later movements. See below

not the Lost Soldier-Ferris district Thrusting probably continues E to Freezeout hills

Age of the Folds:Two points in connection with this: (1) The folds of the Lost Soldier District were not produced by the same forces that formed the Rawlins uplift on which they were supeimposed,but by the forces that formed the Ferris and Seminole Mts. to the N and NE. (uplift) (2) The Ferris and Seminole Mts, are considerably younger than the Sweetwater uplift:they correspond to a relatively late readjustment along its southern margin.

Mesaverde & younger formations within Sweetwater uplift: Flat-lying White R. & Wind R.

Steele & Niobrara

Base of Niobrara to base of Є

Pre-Є

I f these two points can be established it follows that the folds of the Lost Soldier-Ferris district are younger than the Rawlins uplift and younge r than the main development of the Sweetwater uplift.

1. The downfold that structurally separates the Rwlins and Sweetwater uplifts is the sharply fle xed Camp Creek syncline, parallel to the fault along the SW side of the Seminoe Mts. There are no minor folds on the steep north wall of the trough, which is the south slope of the Sweetwater uplift and of the Ferris and Seminoe Mts. The south side of the trough in contrast slopes gently up to the granite axis of the Rawlins uplift. This gentle N and NE slope is interrupted by minor folds, including the long upfold extending from the Wertz dome on the we st, passing thru the Mahoney, Ferris and G .P. domes. The axis of this fold is not parallel to that of the Ra wlins uplift (NNW) but is parallel to the synclinal trough, which in turn is parallel to the Ferris-Seminoe line of deformation. This paralleism indicates t that the upfold is the result either of the same forces that produced the Ferris and Seminoe Mts. or of similarly directed forces. The upfold could not have been the result of the forces that formed the Rawlins uplift.

The north flanks of these minor folds are steeper than the south flanks which checks the notion of force from the NE (asagainst my notion of flow). Fath thinks these minnr folds caused by compressive forces, "thrust" from the north, i.e. fr om the Sweetwater uplift, and to represent the more distant effects of the same forces that for med the Ferris and Seminoe Mts. (How such forces c oul be transmitted through soft sediments and across the trough with unfolde d north flank is not explained).

2. If the Ferris and Seminoe Mts., presumably, by the above reasoning, of the sam e age a s the minor folds, can be proved younger than the Rawlins a nd Sweetwater uplifts, the n it follows that the minor folds are younger than the major Rawlins uplift and than the main development of the Sweetwate uplift.

The Fe rris and Seminoe Mts. are topographically higher than the core of the Sweetwater uplift (Gran ite Mts.), although structurally the latter, at the core of the uplift, are higher than the Ferris and Seminoe Mts. This 2000' difference in elevation cannot be due to erosion alone. The Granite Mts have been smooth ed out, the Ferris and Seminoe Mts. are rugged, showing more youthful erosion. Hence the Ferris and Seminoe Mts. are younger and represent a late readjustment along the south margin of the Sweewater uplift, i.e. the effects of a slight "overthrust" from the north.

How much later is this late readjustement? C.J. Hares (Anticlines in Central Wyoming, USGS Bull.641, 233-279) collected unpublished data on T 28N, Ranges 90-95W, S edgoe of Sweetwater uplift, in connection with work published in Bull.641; also see E.E. Smith: The Eastern Part of the Great Divide Coal Field, Wyo. USGS Bull.3 41, 220-242. These workers find consider able rea djust ment here since pre-Wasatch time, when the major upfolds were first developed This readjustement was possibly as late as White River time (Oligocene) time or even later. The Ferris a nd Seminoe Mts. are local results of this late movement.

3. The Relative Ages of Major and Minor Folding and Oil Accumulation in Wyoming. Max W.Ball. Bull.AAPG vol.5 (1921) 49-63.

Ha s been sa id that major anticlines in Wyoming formed earler than the minor anticlines;that under the influence of mt-build ing pressures most of the oil originally in the shales migrated to the sandstones,and, prior to formation of the minor folds,along the sandstones to the crests of the major folds,from which erosion has since removed it;and that the mino anticlines,those beneath which retace ous rocks are still present,received only suc h small remnants of oil as were left over from the principal migrations.

At first thought natural to suppose minor folds resulte d from dying spasms of the mt-making forces,formed after major folds.Ball has contrary tho'tentative conclusion. Discussion confined to Wyo.E of Green River. Wyo west of Green River in some respects resembles Appalachians more than typical Rockies.

Problem: (1) Wer e minor upfolds formed,in whole or in part,after formation of major upfolds? (2) If so,had the formation and migration of oil mainly c eased when minor upfolds formed?

Classification of Folds: Discussion confined to anticlines;what is true of the upfolds will equally be true of the intervening down folds.

Major f olds:those affecting a large area,or those in which pre-C rocks elevated higher than elevation of adjoining plains.(I would not ca ll these folds). Except fo r Rawlins uplift,s mall but has pre-C core,two definitions the same. All other folds minor folds. (Major folds shown,Plate I,ar e Big Horn, Owl Creek,Wind River,Tetons and to S,Granite Mts.(scatt ere pr e-C),Ferr is-Seminoe,Laramie Mts.,Medicine Bow Mts.,Black Hills at Sundance,NE c orner Wyo.

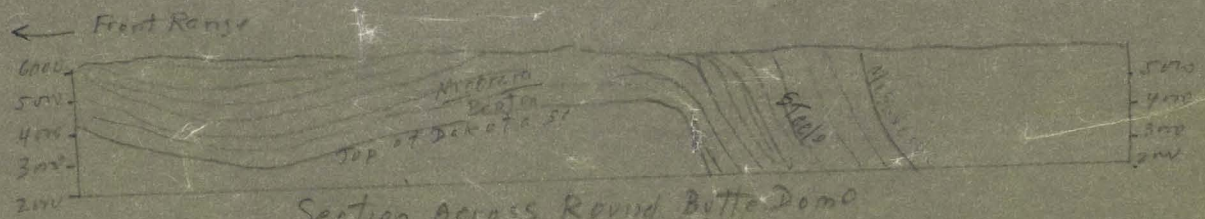
Two classes of minor folds: (1) Those lying along or on prolongations o f the axes of major uplifts,and (2) those lying in the basins paralle l to or at angles to the main ranges,

(1) Axial upfolds:those between S end of Big Horn uplift an d N end of Laramie uplift. Some cause,perhaps presence of or formation of the E-W Granite Mts.,,Bridger-Owl Creek and Shirley-Fre ezeout uplifts,lessened here the forces producing N-S mts.ranges (full of errors:tangential theor y) causing minor anticlines instead of a single great anticline. Here are Iron Creek,Oil Mt., Pine Mt., Powder River Station (NW of Pine Mt.), Emigr ant Gap, N Casper and others. Perhaps following should be included: Tisdale,Castle Creek,Midway,Big Muddy and Salt Creek ,though Salt Creek & per haps the other 4,can equally be included in second class of minor fold s

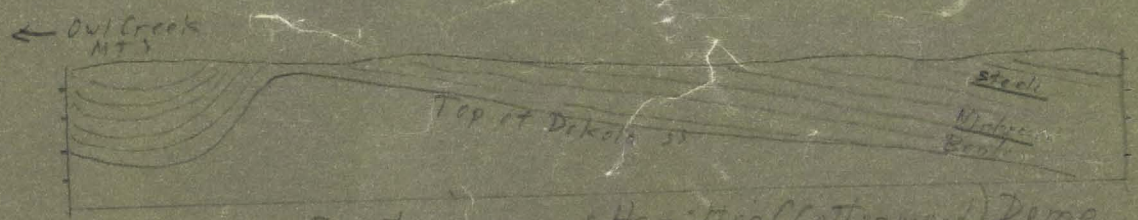
(2). "Basin upfolds". Two types.Commonest,flanks of about equal steepness or has steeper side toward nearest main uplift,with gentler dips toward ca nter of ba sin. Other type,gentle dip toward nearest main uplift,steep dip toward basin. Exceptional type. See Cross Sections.

Lara mie Basin s hows typical arra ngement of basin upfolds.Some folds paralle l major uplifts bounding the basi,some lie at angles to these uplifts.Another typical arrangement,all minor folds parallel bounding ma jor folds, i n S Big Horn Basin.

MAJOR WYOMING UPLIFTS, as shown by outcrops of Dakota & older Rocks.



Section Across Round Butte Dome
Rocky Mt Front, Colo.
Exceptional Type of "Basin Uplift"
(Adapted from Krampert & Ream, Private Report)



Section across Ham Moo (Cottonwood) Dome
Big Horn Basin, Wyo.
Common Type of "Basin Uplift"
(Adapted from Hewett & Lupton USGS Bull. 256)

General Age of Folding: Mt-making forces seem to have started at close of Cretaceous, if not just before; they increased in intensity in early Eocene to a maximum before start of Wasatch. Before 1st half of Eocene was past these forces had spent themselves almost entirely, but ~~xxxx~~ slight local movements a s late as Oligocene. Earliest Eocene seds rest on Cret. with only slightand s cattered unconformity. Next younger Eocene (Wasatch, Wind R., Hanna) is s eparated from oldest Eocene by marked angular unconformity, an enormous amount of folding h aving taken place meanwhile. Great basins filled wi with these younger Eoc ene beds which lie flat in the basin centers, but are usuall y more or less tilted around the edges of the major uplifts, and ~~xxxx~~ arched up on the minor folds. The post-Wasatch b eds run up to and even over both major and minor fold s with out as a rulw shoing more than depositional dips; in a few places they show slight folding. Apparent ly all folding of Wasa tch age or later took place along lines of previous folding.

Evidenc e (see below) that all major folding did not take place at same time: some major uplifts complete by start of W asatch, others still going on.

Relative Age of Major and Minor Folds:

Axial Upfolds.

These pr obably formed at same time as major folds, along whose a xes they lie. Between Laramie and Big Horn uplifts these minor folds occupy an inte rval between major uplifts along same general a xis, and the minor f old folds were probably formed at the time of maximum folding activity. With a minor fold off the end of a major fold (Buffalo Basin fold off S E end of Win dRiver Mts). minor fold may not have been formed until major fold had nearly attaine d maximum height (confusion between folds and uplift). Buffalo Ba sin minor fold was well advanced and 3500 -7000' of beds had been eroded prior to deposition of Wa satch, but folding c ontinued into Wasatch, tilting basal Wasatch beds s.t. as high as 30°. In adjoining Wind River major uplift an additional 8000' bed s had been eroded prior to Wasatch; in plac es discordance in dip is grea ter than in Buffalo Basin. Buffalo Ba sin fold formed before Wind River fold completed. Minor axial type upfolds formed at same time as major folds along whose axes they lie.

Basin Upfolds: Common Type.

Not easy to fix relative age of common type of folds lying in the basins parallel or at angles to the main uplifts. Only marker to judge b y is base of the 2nd Eocene sries (Wasatch etc.). One plac e where conclusion can be drawn is Simpsons Ridge fold. Hanna formation (Wasatch?) lies on N end of Medicine Bow uplift at 4-5°, across edges of older sed s. tilted as high as 80°. On Simpson s Ridge Hanna dips 1-60°, 5 to 40° less than that of older seds. On S flank of Freezeeuts Hanna vertical or overturned in accordance with the older beds. Hence major folding not all same age. Since Freezeouts E-W, c ross str esses here did not staet until main stresses had almost ceased . Simpson s Ridge fold nearly N-S must have been s tarted b y main E-W stress es and c ompleted by the later cross stresses. If so, its initial fold ing pr obably contemp. with Medicine Bow folding, its final archi ng contemp. with that of the Freezeouts. This minor fold began during formation of the oldest major folding and grew further during youngest major folding.

Theoretical Considerations: Wyo seds constant in nature over wide areas. Competent and incompetent beds alternate in straigraphic column, but lateral variations in competency not important. "We can safely assume that mt-making stresses were mainly hprizontal, or, more accrately, that the horizontal componets of these forces were much larger than the vertical components. Indeed there is some reason for believing that the vertical components were almost neglible. From the predominant north-south trend of the main range it is evident that the main hprizontal stresses were east-west, but the presence of east-west and diagonal ranges shows that there were cross-stresses." (p.5 6).

If considerable thickness of seds of relatvely uniform areal competency subjected to compression, beds would begin to buckle in a number of places esp. if stresses not all parallel. Smal folds first result normal to main stress but modified by the cross-stresses. 1st stage.

P continues, one of small folds expected to grow more rapidly than the rest, thru local variations in competency or local concentration of stress. This would be line of greatest weakness along which later stresses normal to its axis would be relievd. Further stresses in same direction increase height of this fold, not changing much smaller parallel folds. At same time minor fold due to continuing cross stresses would continue to grow at a rate that, depending on relative positions, might be either increased or decreased by the major folding. Hence a major fold, a series of minor folds parallel to it and formed mainly before it attained major proportions, and perhaps a series of minor folds at angles to the major fold and formed contemp. with 2nd Stage: all minor folds at least as old as major folds.

P continues beyond second stage, major uplift might gradually become a close fold, developing into a line of strength instead of one of weakness. As this took place continuing stresses would develop a new era of minor folding, probably along parallel minor folds already started, until one of these folds became a line of max. weakness, after which it would develop into a major fold and the other parallel minor folds would again become stationary. The minor transverse folds would continue their gradual growth unless so situated as to be absorbed in the new major uplift. This is 3rd stage have minor folds formed partly before, partly contemp. with and partly after the major folds to which they are parallel, and other minor folds at angles to the major folds and contemp. with them.

W. van W. van der Gracht suggests a 4th stage, observed in intermontane basins, in which, after completion of 3rd stage and consolidation of the major folds into stable masses, seds. subsequently accumulated in the basins have been subjected to a further period of folding, folding the seds, parallel to the basin rims and not necessarily parallel to the major folds. In this stage the minor folds in the younger seds are much younger than the major folds ot than the principal minor folding in the older seds.

What theoretical stage of folding is represented in Wyo? The major folds show the 1st stage is passed. Two factors show 4th stage not reached: (1) the few hudred feet of seds deposited since the main mt-making movements not as a rule affected by later folding. Around edges of the basin they have as a rule been somewhat tilted by continuing movement of the major uplifts (by lateral compression?), and here and there similar movement of a minor fold has tilted the younger sediments, but nowhere do the younger beds show signs of folding except in connection with movements started long before their deposition. (2) Minor folds in the true basins do not all parallel the basin rims. In S Big Horn Basin they all lie parallel to the bounding major uplifts; ib Laramie Basin they lie partly parallel, partly oblique to the

major uplifts;in neither case do they all parallel the basin rims.

p.59: "The absence of closed major folds indicates that Wyoming has not reached ev en the third stage.Along some of the mountain faces the sediment ar eies a r e steeply tilted and here and there overturned.Faults of some magnitude have been developed,but nearly all of these are normal,not thrust faults.In general the seds.lie on the flanks of the major uplifts at relatively low angles.The intense flank crumpling of the Appalachians is not present here.With the possible exception of the small east-west Ferris-Seminoe ranges there seems not to be a close major fold in the State."

Henc e Wyo in 2nd stage or at most between 2 a nd 3,and the minor basi upfolds of the common type were formed nefore the completion of the major folds.

Excepti onal Type of Basin Upfolds: Common type shows either symme trical fold ,or more commonly,the dip toward the nearest major uplift is steepe r than that toward the basin.A few folds in Wyo and adjacent Colo have gentle dips toward the mts.and steep dips towar d the basins. If we accept common a ssumption that gentler slope indiaates direction from which P came then these folds (exceptional type) were formed by stresses acting from th mtwa rd side (and conversely, common type formed by stresses acting from bottom of basins).

Hors e Creek fold, 30 mi.N of Cheyeane,lies just E of Fr ont or Laramie Range.W o f this s tructure,along the Mt. front,seds are nearly vertical,in plac e s overturned,faulted or both. On the oppos ite (east) side of the Ra ngeseds. dip 4-12°.p.60:"If we accept these facts as indi cating that the thrust forming the range came from thr west.then the Horse Creek structur e might have been due to the pushing of the whole mountain mass a short distance toward the east. It is hard to believe,however,that this would take pla ce without much more closing of the major fold than has taken plac e."

Near Round Butte ,Colo.,30 miles S of Horse Creek (See Se ction) a similar fold,beds dip steeply toward plains,gently toward mts.But here adjacent east flank of mts. gently inclined east (5-25°)-no shoving E of mt. mass.We c an therefore dismiss shoving as cause of these folds.

Two probables causes remain;assuming folds caused by stresses from side where mts. now are (1) either formed by Ps acting prior to formation of the major uplift (note uplift synonum ous with folding) or (2) they were formed b y stresses induced by resettling of the major uplift,probably after it reached its greatest height.With (1)the folds differ from the common basin upfolds only in that the major uplift developed behind instead of in fr ont of the m,and the folds ar e as old as the major uplift. With (2), the fold s were formed after the major was well advanced.

Above based on assumption stresses came from low-dip flank. Dr.E.F. Davis however tells him Hobbs and others expe riments show that in some places P may hav e come from steep-side dip side. If true here,these exceptional fold s are similar in origin to common type (P c ame from ba si ns -E.W.) Since the adjacent major uplift is not a closed fold,these minor folds must be considered as old as the major uplift.

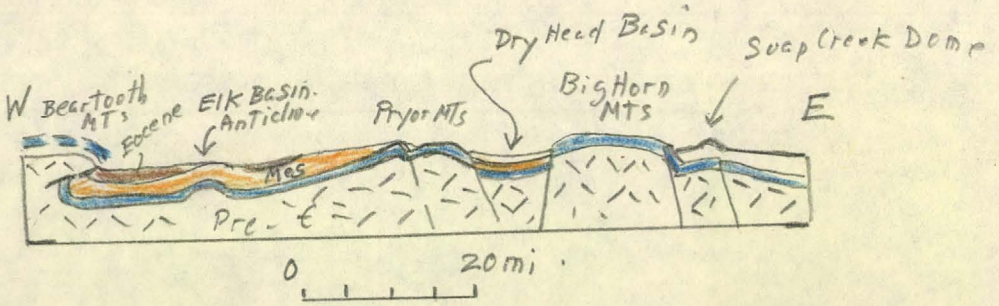
Relative Age of Oil Migration: It has been concluded,tentatively that nearly all or all the Wyo minor folds were formed during time of formation of nearby major folds. But even if all major folds first,all minor folds later,it does not follow that any material part of the oil originally present in the rocks migrated to the major uplifts before the minor folds were formed,and thus was subsequently lost thru erosion.

Formation and collection of oil involve (1) distillation of organic material in oil shale;(2) pa ssage of oil from pt.or origin in sh to adjacen t ss;(3) migration of oil alon ss to crest of upfold or other trap.(1) and (2) take longer tha n (3);all require muc h time.Assuming longest probable inter val between folds and greatest probable acceleration of distillation and migration due to heat asso ciated with mt-making movements ,not likely that migration had proceeded far befor e latest folding took place.Borne out by fact that folds farthest from the major uplifts have the most oil.

If major folds had bee n formed first,minor folds next to them would have been for med next,and those farthest from major folds,last.IF oil migra tion were underway in th e meantime major folds should have accumulated the largest quantity.those nearest them the next,etc. Am't of oil accumulated would varyndirectly with r elative age,inversely with distance from major fold. If on the other hand,all folds formed at same ti m e and oil migration had not progre ssed fa r before formation of last fold,the outermost folds, being acc essible to the basins supplying the oil,would get the most oil;fol folds secluded behond these basinward folds would get only such quantitie s as their limited drainage areas could supply. This is the ca se.Basinward folds if othe rwise favorable ar e rich in oil or gas;inner folds less . Clearly the minor fol d s formed before oil migration along the ss was well under way.

Concluions: Tentative. (1) Bearly akk Wyo minor folds formed during period of for mation of major uplifts.(2) Nearlyall Wyo minor folds for,ed b befor e migration of muc h oil. (3) Minor folds received their relativ shares of the oil formed,and am't in each case depending on richness of sour ce,drainage area and circulation conditions.(4) If some Wyp folds dis appointing reasons other tha n realtibe ages of folding and oil migration must be sought.

4. Results of Structural Research Wor k in the Beartooth-Bighorn Region,Montana and Wyoming.W.H.Bucher,R.T.Chamberlin,W.T.Thom Jr . Bull.AAPG vol.17(1933) 6 80-693.



Structure Section across Beartooth,Pryor and Bighorn Mts.(Approximately along 45 th Parallel). After R.M.Field et alii:Yellowstone-Beartooth-B ig Horn Region.16th In t.Geol.Cong?(1933)Guidebook 24,Fig.11,p.50.

Resul ts: (1)" The na ture of the individual structural features studie d indicate that they are the products of basement block or wedge elevation,or rotation under regionally applied c ompression—rather than products of simple folding under tangential com pression"(p.689).

(2) The merging of monoclines into thrust faults,and the magnitude of the thrusting,both seem directly related to the extent to which the basement r ocks hav e been ele va ted in the uplifted (and over thrust)structural element.Thus in the Pryor mountains,where relative uplift of the northea tsr en corn e of the southeast block is about a mil e ,overthrusting is incipient.On the west flank of the Big Horn Mountains ....where relative uplift is about two miles the (w estward) overthrusting is of the order of magnitude of half a mile.On the east si de of the Big Horns,

south of Sheridan, where the uplift is c onsiderably greater, the (ea st-w ard) over thrusting is much more extensive, and similarly along the Bear tooth Front between Clark Fork and Canyon and Nye the area of maximum overthrusting seems closely conn ected with the loc us of maxi mum elevati ion of the crystalline core of the uplift," All quote to here. IMP.

3? (4) Join t systems developed in the pre-C complex involved in the o-verthrust...indicate that the sharp flexing in the u pper surface of the granite induced by dr ag attend ing the thr usting, has been accomplis hed by distributed movement on joints, and has not resulted from any recrystal-lization or "flow" in the granite.

(5) Small porphyritic intruions found along the tr aces of thrusts sur-rounding the Beartooth uplift; porphyritic stocks, d ikes, sheets cut the old er crystallinies i n the c entral part of the uplift. (p.693).

5. Faulting in the Rocky Mt. Region. J.S. Irwin Bull. AAPG 10-2 (1926) 105-129. See" Fractures Patterns-Uplifts-Domes II". Deals with epi-anticlinal faults: minor normal faults in parallel or radial systems confined to the crests and flanks of anticlines and domes of the mountain type, i.e confined to upfolds. Use quotes from this in BOOK.

The Relation of Deep-Seated Faults to the Surface Structural Features of Central Montana.

W.T.Thom Jr. Bull AAPG 7(1923) 1-13.

During late Cretaceous Montana and Wyoming must in many ways have paralleled conditions now present in the East Indies. See H.A,Brower: The Horizontal Movement of Geanticlines and their Fractures near the Surface. JG 29 (1921) 560-577. There the depressed area between the Asiatic and Australian contienents shows concentric mt. arcs as chains of islands separated by sea deeps. Some of these islands show "compression" and "thrust" faulting; Bighorn-Big Snowy and Black Hills-Porocupine dome-Little Rocky lines may have been similar tho lesspronounced island arcs in Jurassic-Cret.

Evidence (stratigraphic,which he cites) points to existence of local uplifts in central Montana in later Paleo and Meso time.(He mentions early upper Cret.: Crazy Mt.,Bull Mt. synclines, Prcupine Dome,Cat Creek-Devils Basin horst. More marked uplift at this time in Bighorn,Pryor, Big Snowy Mts. Yellowstone Park Plateau in lower Cret.uplifted,i.e. earlier uplift on the W. Slight growth of Bighorn "fold" in late Jurassic and earliest Cret. Angular unconformity between Jurassic and Carbon. in Big Snowy and Little Rocky mts,suggests still earlier uplift. Pre-Penn uplift of Bighorn and Big Snowies) Trend of these early uplifts may have been about E-W.

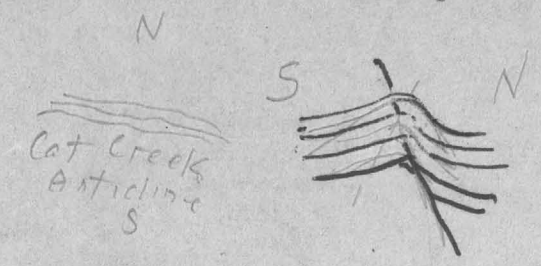
In central Montana a number of strong asymmetric anticlines roughly parallel to Lake Basin fault zone 100 miles long across S part of area.

Dominant structural feature Big Snowy Anticlinorium which includes Porcupine dome on the east;Big Snowy Mts. and Judith Mts. on the anticlinorium; Little Belt Mts. a slightly offset W continuation of same major feature. Crazy Mt.,Bull Mt. and Blood Creek synclines are pronounced structural features. Little Rocky,Mocassin and Judith Mts are laccolithic uplifts.Highwood and Crazy Mts. products of vulcanism and of dike and plug intrusion.

Seems to indicate that structure of surface rocks has a relationship

to faults in the basement complex (Fath, USGS PP 128C, 1920) and that movement of crustal blocks bounded by these fundamental faults had an important role in determining attitude of overlying strata.

Thus only plausible explanation for the uplifted area between Cat Creek and Devils Basin anticlines is that this area represents a horst in the basement whose N edge is marked by the abrupt downward slope of the seds forming the N limb of the Cat Creek anticline and whose S edge is similarly marked by the steep S limb of the Devils Basin anticline. That these marginal asymmetric anticlines overlie faults below is indicated by development work in W Dome at Cat Creek; drilling shows that crest of arch in Cat Creek sand does not lie S of surface crest of the anticline and that it is probably somewhat offset toward N or steeper limb; can only mean the asymmetric anticline in surface rocks passes into a fault at depth:

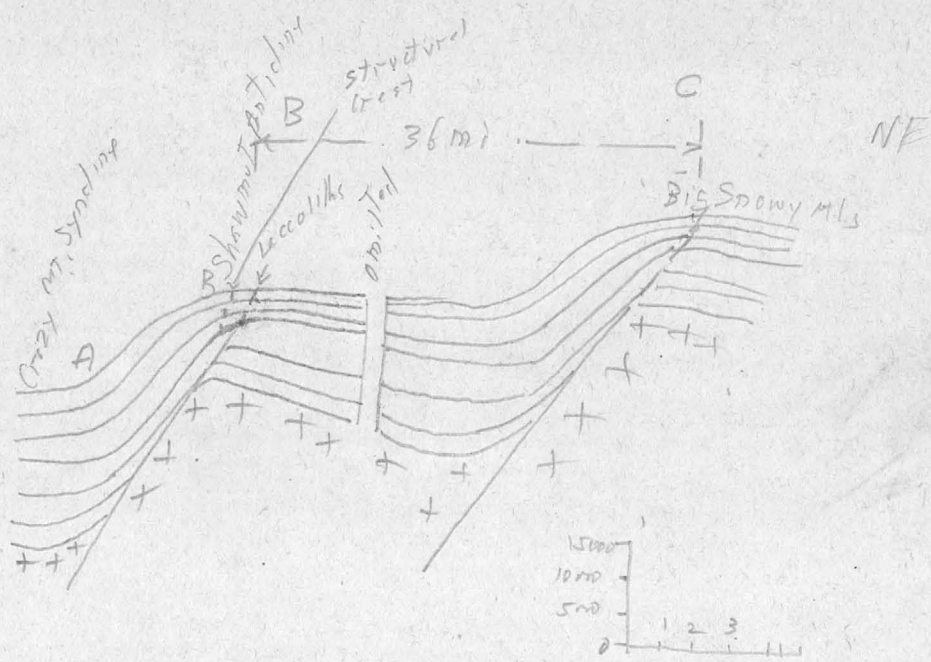


Reasoning on this, steep SW limbs of Pole Creek and Woman's Pocket anticlines and of the Big Snowy Mts. and Little Elk-Big Elk-Shawmut uplifts are also produced by other basement faults also NW-SE.

The Lake Basin fault zone also probably surface expression of deep fault, horiz. movement S side E. See R.T. Chamberlin: A peculiar belt of oblique faulting. JG 27 (1919) 602-613.

The thrust faults of west-central and SW Montana (apparenetly he means Lombard and Beartooth thrusts etc.) are thought to have disaipated the intense compression which otherwise would have affected the outer shell in central Montana; but it is thought that deeper part of crust was subjected to enough stress to pruduce differential movement of great blocks of the basement, whether prevuously outlined or not by deep-seated faults. Magma injection also took place either coincident with or subsequent to this crustal block movement. Altho margins of these deep-seated fault blocks altho somewhat masked by overlying seds are clearly indicated by visible structure of region. Cat Creek-Devils Basin horst has been elevated relative to its surroundings, slightly tilted toward E. In contrast, Crazy Mt. syncline formed by ablock depressed by transfer of material from a subcrustal to supercrustal position thru volcanic eruptions. In the main however the deforming stress has produced a slight rotation of the blocks without greatly changing their average elevations. One such rotated block; outlined by fault zone S of the Hailstone Dome, by the line of steep dips E of the dome, and by the triangular area, depressed. between the Womans Pocket and Shawmut anticlines.

The main uplifted portion of the Big Snowies and the Womans Pocket anticline seem to be similarly rotated crustal blocks; the Little Elk and Big Elk domes and Shawmut anticline believed to lie along the S edge of a 4th tilted crustal block ehose N and W margins are shown by the steep slopes of the Big Snowy and Little Belt mts.

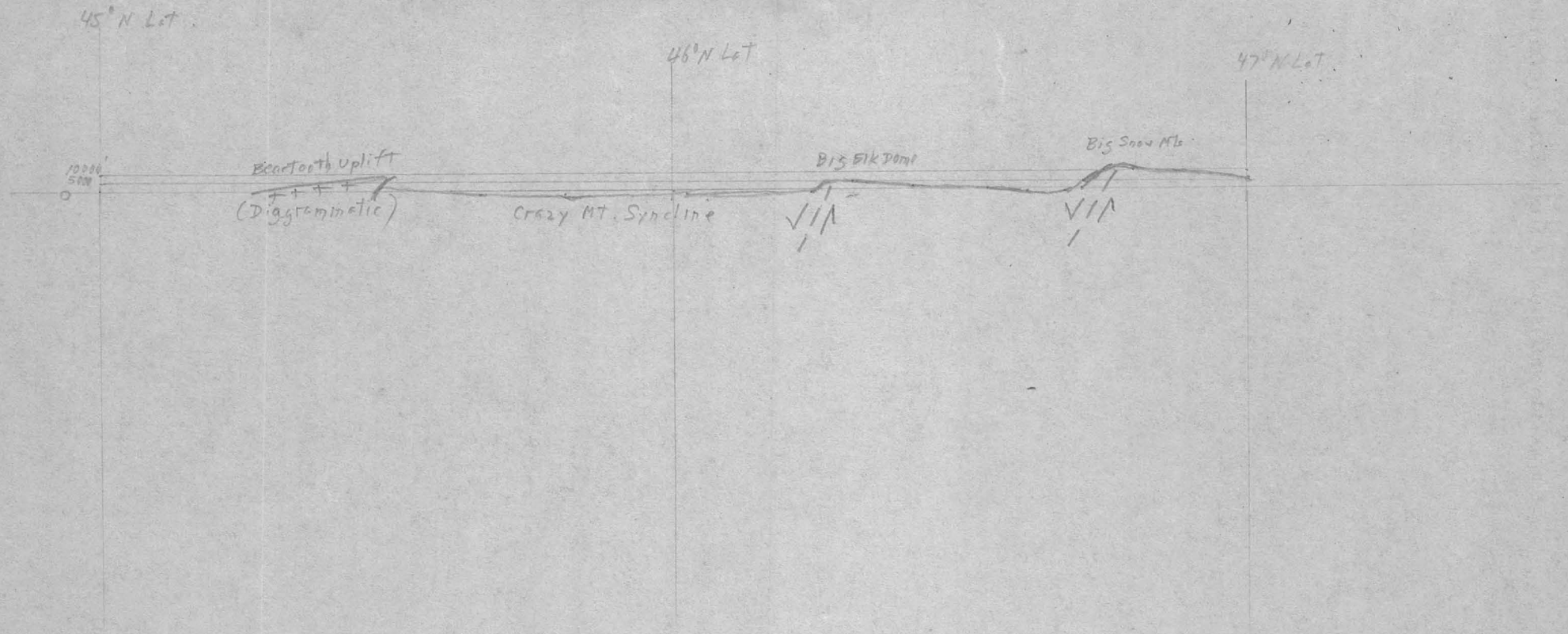


The plane of weakness formed by the upward extension of a deep fault is assumed to be the natural path for rising magmas;this plane intersects the surface at a ~~xxxxx~~ distance from the steep limb of the anticline ,corresponding to the position of the Big Elk, Little Elk and Shawmut domes,almost certainly of laccolithic origin.

In summary, uplifts,probably E-W,developed in Montana during later Paleo and in Mesolithee,acting as resistant buttresses,caused a W-shift on the zone of Eocene thrusting believd to be continuous from the Lewis thrust at least into Utah.

Notes: This central Montana area seems to be an area intermediate between the Beartooth-Bighorn plateau region,where Thom's "deep-seated" faults may be seen ,and the Bannock trough area,where the basement is overlain by thick seds.that do not directly reflect deformation in the basement below. Why should there not be similar crustal readjustment by block faulting, horsts and graben etc.,where sediments were thicker? In considering compressive stress,lateral,why should it be "stronger" where seds. were thick and weak and readily folded and thrust, and "weaker"where seds were thin and the basement platform lay close to the surface?

Following the ideas of Thom the indicated faults and blocks have been put on the tectonic map of North America;with the exception of the Cat Creek-Devil's Basin horst,all the "rotated" blocks are tilted gently N and faulted "normally" on their S side-typical tilted step-fault,Basin Range blocks. A section drawn to scale (top of Dakota ss) thru the Big Snowy Mts.,Big Elk Dome,Crazy Mt, Syncline and Beartooth uplift reveals a typical uplift structure. The axis of the broad uplift coincides with the Crazy Mt. syncline, a graben on the crest;Thom's concealed faults are the antithetic faults on the N side of the uplift. The tilting of the Beartooth uplift, down gently to the SW,conforms to the uplift,SW flank;but here ,instead of a normal fault dipping N,there is a steep reverse fault overturned in places to a "thrust". Hence this SW flank of the uplift is not simple,like the NE flank,but complicated by individual autonomous movements,the upshoving of the Beartooth and Bighorn etc. ranges.


45° N Lat.
46° N Lat
47° N Lat.
10000'
5000
0
Beartooth Uplift
(Diagraminetic)
Crazy Mt. Syncline
Big Elk Dome
Big Snow Mts

Scale: 1" = 20 mi.

The Crazy Mt. volcanics came up along the crest of thisWNW arch; it may be as Thom surmises,that the Crazy Mt. syncline is a sag trough formed by transfer of material that came up along the crestal plane of the arch,from below the surface to on top of the surface,and that therefore the syncline is not a true graben.

Thom says that the Yellowstone Plateau SW of the Beartooth Mts.was uplifted as early as the lower Cretaceous;omitting periods earlier than this as too far ahead of the Laramide revolution to have any direct connection,this suggests a start of uplift in the W or SW part of the region;growth of the Cordilleran geanticline eastward. The synthetic fault represented by the Beartooth thrust may therefore have originated early. Subsequent general uplift,spreading to the NE to form the broad arch mentioned,found this fault there.The Beartooth range and the preexisting fault particippated in this later,broad arching. If the Crazy Mt. syncline is a true graben,or even if it is a sag trough it would behave like a graben if along the crest of an arch,i.e. it would sink to hekp stretch the crust (Big Elk Dome graben fauult). While sinking on the SW side,next the Beartooth NE front,would not similarly assist crustal stretching over the arch,it would nevertheless sink thru prompting on its nE side. Hence the Beartooth unit would rise,participating in the arching;the block then SW of the Beartooth fault would rise,while the Crazy Mt. syncline would sink.Being full of incompetent seds. it would causse the fault plane to flow and turn into a "thrust".

General:It would appear from the Tectonic Map of W. N.America that the spread of the Cordilleran geanticline eastward had as its core or nub the Colorado Plateau, so long a positive block;just as the rise of the Uncompahgre-San Luis geanticline at the same time had the broader San Juan upland . The general uplift may have grown north from the Colorado Plateau and in roughly concentric waves away from it;one of these NW waves was the Yellowstone Plateau region,and a succedding wa wave was the arch described.

Relative Age of the Heart Mountain Overthrust and the Yellowstone Park Volcanic Series.

C.J.Hares: Proc.GSA for 1933, 84-85.

New facts on the stratigraphic and structural relations of the late Tertiary aggolomerate of the Park Series and the Paleozoic ls.involved in the Heart Mt.thrust at Cody.

The question is,what thickness of overburden held less than 1000' of ls.together while being moved 30 miles?

Note:This is very important.Cf Loverings criticism of Bucher in this symposium. Probable that no physical concepts would permit thrusting of such thin sheets so far;creep from uplift down into basin only physically sound conception. Search for an overburden to confine the thrusting stress probably unsound. Cf Balk comment on Pachuca paper, Red Rock and New Ahaden horizontal movement with no cover.

An enormous unconformity,herein named the Shoshone,equivalent to 15000' of beds,occurs between the Madison ls. and the late Tert.agglom. This unconformity was thrust with the Paleo ls.In the Bighorn basin,pebbles with Paleo fossils now found in the Cloverly,Frontier and Wasatch formations show that the area of this unconcormity was the feeding ground for streams supplying these sediments and that the Shoshone unconformity was developed during the Cret.-Early Tertiary.(I.e.uplift of the Paleozoics).Porphyry pebblesin both the Frontier and the Wasatch formations came from the Beartooth Mts.,showing clearly that these mts. were then a landmass. It is concluded that the Shoshone unconformity and the Beartooth "Plateau" are in part contemporaneous.

It is believed that this agglomerate was the overburden that held the thrusted masses of thin ls. together. The bedding of the agglomerate and the limestone.parallel,is well shown in Logan and Sheep Mts. Secondary faults displace both agglomerate and limestone;"they were apparently contemporaneous with the main overthrust". Partly metamorphesed isolated chunks of Paleozoic limestone far up in the agglomerate in Carter Mt. indicate they are of volcanic ejecta origin. Granite boulders in the agglomerate may have the same origin. Rounded,faulted,crushed quartzite pebbles beneath the limestone in Hear and Sheep Mts.show the thrust masses moved out over a gravel-covered land.

It is tentatively concluded that the disturbance continued from the Miocene into the Pliocene.The cause of overthrusting may have been the great volcanic activity of the Yellowstone Park district.

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Geology of Logan Mt.Wyo.and its bearing on the Heart Mt.Overthrust.
Robt.A.Laurence,M.M.Sheets.GSA Proc.for 1933,93-94.

Recent detailed studies of the Logan Mt.area have brought out the following on the Heart Mt.Thrust.

The overthrust block is made up of Bighorn ls.,3 Forks shale and Madison ls.The base of the block is most often in the Madison.The N and W portions of the fault plane lie at 8000' elevation;the plane drops to 6000' near the middle of the area.

Geol. of Logan Mt. Cont.

The overthrust block is highly shattered and contains many small normal faults and a few thrust faults. An erosion surface of considerable relief developed on the overthrust block, deep enough in places to expose the Cretaceous shales which underlie the thrust. Later this erosion surface was largely covered by Tertiary volcanics.

Along the front of Logan Mt. the Cretaceous beds lie almost undisturbed, dipping gently W. In Trout Canyon the thrust plane is faulted 400 ft. by the minor faulting so characteristic of the overthrust block. In a few places the overlying volcanics are affected by this faulting.

SYMPOSIUM: RESULTS OF GEOLOGIC RESEARCH WORK IN THE YELLOWSTONE - BEARTOOTH - BIGHORN REGION.

GSA Proc.for 1933, 55-60.

II, Pre-Cambrian Structure of the Beartooth, the Bighorn and the Black Hills Uplifts, and its coincidence with Tertiary Uplifting. P. 56

Ernst and Hans Cloos.

Reconnaissance studies of above regions made in 1933. Although differing individually in every detail, the three structural units seem to indicate a coincidence between pre-Cambrian doming and their present boundaries.

The Beartooth uplift shows parallelism of gneissic structure and bordering major faults at its south end. Axes of folding indicate a pre-Cambrian dome plunging toward the south, but at an angle steeper than the overlying sediments. The gneisses are dragged in a narrow zone along the Beartooth fault.

The Bighorn uplift contains a granite core corresponding to the present highest parts of the range, surrounded by a mantle of schist, locally poorly preserved or merely suggested by the increasing number and size of inclusions in the granite. The bordering faults are parallel to the primary granite structure, and flexures often transgress it. Basic dikes indcate an up-doming of the pre-Cambrian with its culmination within the granite core.

The Black Hills consists of a complete pre-Cambrian dome with a granitic center and a schist mantle. The long axis coincides with the present axis of the uplift. The schists dip away from the granite; their dip increases outwards and is reversed at the margins of the uplift. The axes of folding plunge northwestward and southeastward in the direction of the present uplift axes.

SYMPOSIUM, IV. GSA Proc.for 1933.

Problem of the Heart Mountain Overthrust.p.57.
W.H. Bucher

"Everything points to an origin of these thrust masses different from that produced by normal orogenic movementsmand possibly connected in some way with the extraordinary volcanic activity of the region."

Attention is called to Ries basin, south Germany,where overthrusting has taken place radially ouward from the relatively small basin.Structural relations make it practically certain that volcanic explosive forces were the chief cause. May the Heart Mt.thrust be ascribed to the same causes? The present Shoshone R.valley was the scene of extraordinary volcanic activity.

Important facts:

(1). Three larger thrust masses are cut by normal faults,many of these evidencing horizontal movement from the north.

(2) 3 smaller masses (E and S of the main sheets) are extremely shattered. Two of these consist of several blocks of ls.of different age piled side by side;the 3rd has been largely disintegrated into weathered fragments.

(3) On the W,along the inner edge of the main thrust masses large and small limestone fragments are contained in the volcanic agglomerates. Some form conspicuous cliffs,their sides streaked because of immersion in the agglomerates.

(4) Quartzite pebbles in unconsolidated,pre-volcanic gravels beneath several of the thrust masses are fractured peculiarly or show curious shatter marks.

Discussion: T.S.Lovering: Bucher spoke of gravels onwhich the Heart Mt.thrust fault rests as containing no volcanic rocks,thus indicating that the thrust is earler than the volcanics.Lovering thinks on the contrary that the lack of volcanics in the gravels indicates that the gravel preceded the volcanics and not that the thrust faulting preceded the volcanics. Lovering asked if Bucher had considered the strength of the rocks that would be necessary to stand up against the initial momentum given to these huge masses in moving 20 or 25 mi.without almost completely disintegrating the masses.

Bucher (hysterical): I ask Lovering to tell us how he could move a mass of that thickness over a relief of say 2000' without considering the strength of the rock if he intends to push it laterally.How could Lovering push such a sheet with or without overburden across that surface,as irregular as it is today,without the mass yielding to shearing within itself? We cannot one wor this question.

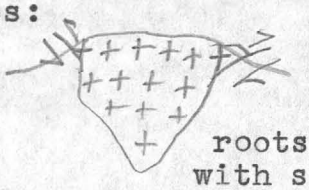
SYMPOSIUM. V.

Results of Recent Studies of Certain Type,Space and Time Relationships in the Yellowstone-Beartooth-Bighorn Region. W.T.Thom Jr.et alii op.cit.p.58.

Results of Recent Studies etc.cont.

"Trap-door" and horst-like uplifts are characteristic of the region; true folding is practically absent. "The general forms and positions of present mountain uplifts were apparently determined by the position and forms of pre-Cambrian granitic intrusions--these granites yielding to Laramide stresses differently than did the metamorphic host rocks into which the granites had been intruded (Cloos)."

The two-directional (basinward)thrusts on both flanks of the Bighorn and the Beartooth ranges indicate that these faults are really underthrusts, resulting from the jamming of the basin sectors benath the rising mountain wedges:

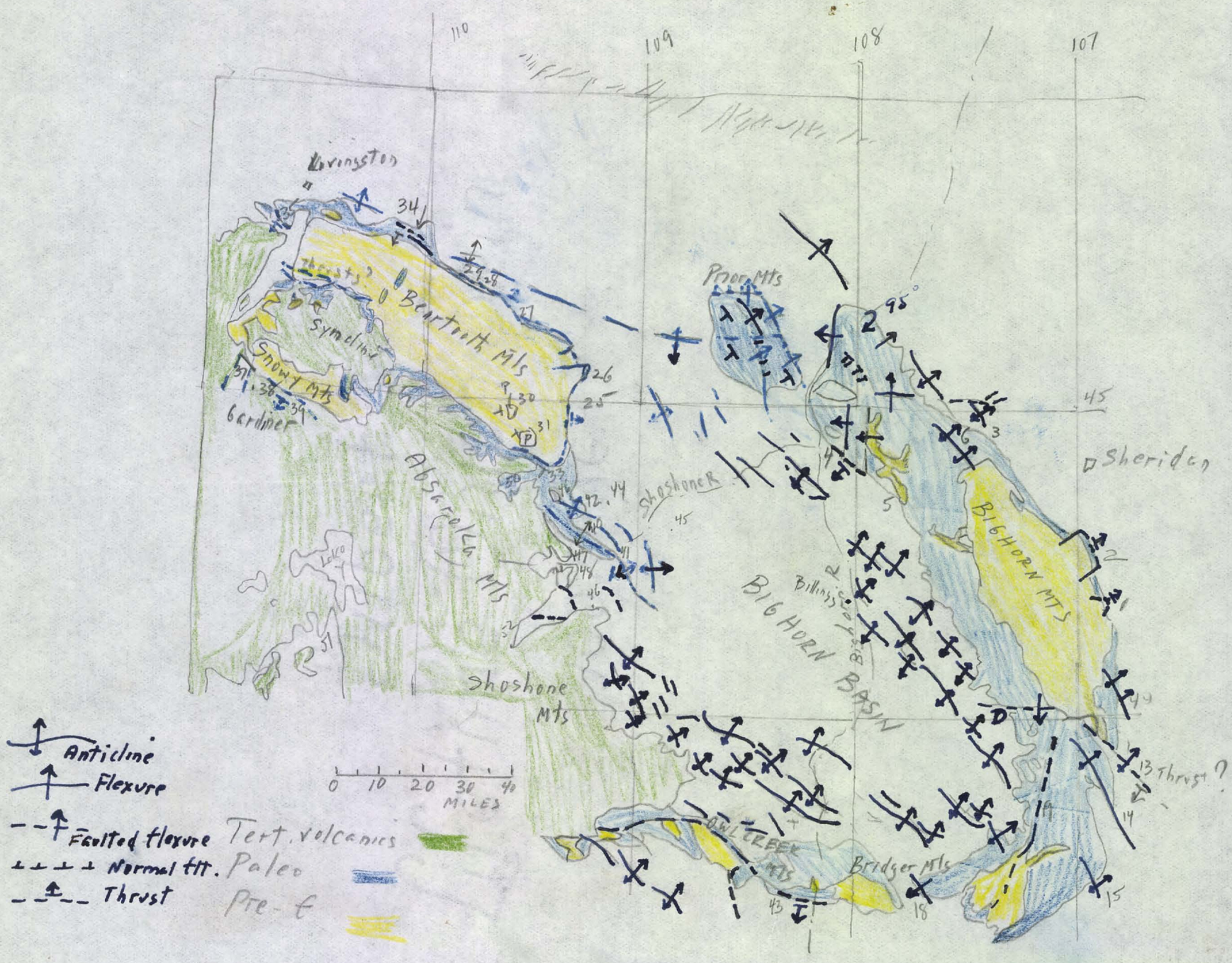


The competent granitic massifs of the mt.uplifts appear to have had relatively shallow roots. (Note: That the mt.massifs are wedges with shallow roots appears to be solely a consequence of the theory of underthrusts).

Gravity studies show that conditions in the basin areas are consistent with the theory of isostasy,but that the mountains have been pushed too high for isostatic equilibrium ,by forces other than isostatic (Chamberlin). Straitgraphic studies show that the Laramide deformation was incipient in this locality in the early Upper Cretaceous;it progressed by recurrent movements of increasing intensity to a maximum at the end of the Paleocene and probably continued, diminishing,thru the Eocene.

Physiographic studies indicate that there probably has not been differential uplift in the local mts. since a remote (pre-Miocene?) time,in spite of great erosional unloading.

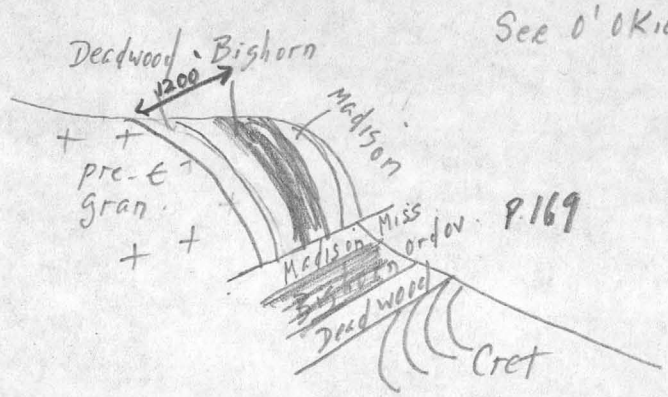
The southward thrusting near Livingstone Mont. may be Miocene.


110
109
108
107
45
Livingston
Thrust?
Beartooth Mts
Syncline
Snowy Mts
Gardner
Absaroka Mts
Lake
Shoshone R.
Prior Mts
Sheridan
Big Horn Mts
Billings
Big Horn Basin
Shoshone Mts
Owl Creek Mts
Bridger Mts
Thrust?
Anticline
Flexure
Faulted flexure
Normal flt.
Thrust
0 10 20 30 40
MILES
Tert. volcanics
Paleo
Pre-€

Geologic Problems of the Beartooth-Bighorn Region.

W.H.Bucher,W.T.Thom Jr.,R.T.Chamberlin. Bull.GSA 45 (1934)167-188.

I. Structural Problems (Bucher). The region is one of peculiar structural types;elongated uplifts alternating with basins ;~~which~~ block faults are combined with folding.

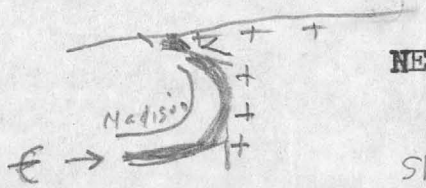


NE front of Bighorns (Locality (2)).

The central part of the Bighorns is the simplest.~~On~~ The SW side is mantled by Paleo seds.chiefly ls,which descend toward the Bighorn Basin in long,gent,e dip slopes.On the east side the Paleo seds.drop off toward the plains steeply. At localities (1) and (2),local overthrusting has pushed out lobes of the crystalline core onto seds.of the foothills.As the axis of the crystallines of the central region plunges N the dips of the NE flank become less steep,dropping to 10°-20°at (3).Beyond here,in the N part of the Bighorn mts.the structural pattern is reversed (suggests differential uplift by sag of basins,see Plate IV-1: steep front of Bighorn Mts. on east flank is opposite deepest part of Powder River basin on the east,while the steep front on the W is opposite the deepest part of the Bighorn basin. The thrusts go with the steep front and lie opposite the deepest parts of the basins in each case. The positive factor might have been sag of the basins rather than uplift of the mountains, which might accord with Bauer's notion of low elevations during main Laramide deformation.) In the N part,the crystalline axis outcrops close to the SW flank and the Paleo seds lie on the NE flank (1/2)of the range with gentle dip slopes;in contrast,they drop off abruptly on the SW side.Locally beds are even overturned in that direction.At (4) for instance folds are overturned 60°,locally even 90°,so that they dip 30° to almost 0° NE,i.e. into the mt.front in inverted position; locally this overtruned limb mergesinto an overthrust:

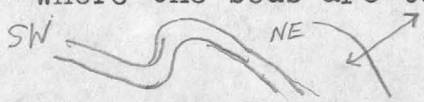
CLINGH-
ER

SW



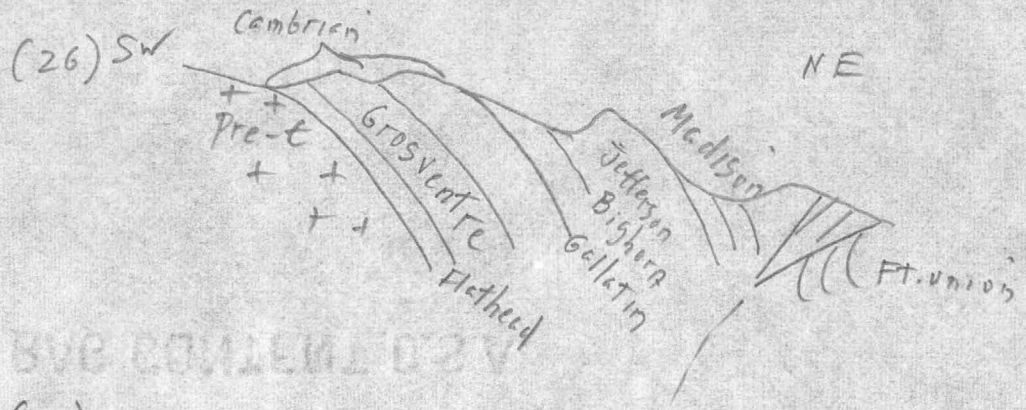
NE

On the NE side of the range in this N part of the Bighorns,among the gently inclined beds of the dip slope the Dry Fork anticline (6) is strongly assymetrical,the steep limb facing SW, where the beds are turned up vertically:

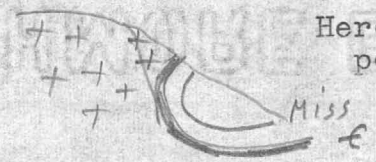


Pryor Mts.: Two pairs of flexures (1) E-W and (2) NNW, divide this uplift into 4 units.

Beartooth Mts.: Thrusting along NE front



(29)



Here beds dip into the mts. 20o-30° in inverted position.

The larger part of the Bighorn mts. W and SW of the mt. front between (25) and (29) forms a long gentle dip slope (SW dip). In the S part, remnants of Paleo seds. lie as warped or flat sheets dipping gently Sw (30,31).

The S end of the Beartooth mts. consists of the plunging end of a large anticline. Apart from this, the S section of the Beartooth Mts. offers a close parallel to the central section of the Bighorn Mts. Both are large uplifts steeply upturned and overthrust on the NE, with the SW slope a long, gentle dip-slope. As in the Bighorns, the structural pattern is reversed in the NW section of the Beartooth mts. Westward from a point just west of (29), the Paleo seds. of the NE front dip NE at relatively gentle angles and are thrown into a series of assymetric folds, the steep fronts of which face SW. Locally these folds pass into small thrusts overthrust to the SW (34). Overturning to the SW and thrusting to the SW prevail along the entire N front of the N section of the Beartooth Mts.

The Snowy Mts. uplift ends on the SW with a sharp flexure, at least locally overturned and overthrust to the SW (37), (38). This is a high-angle thrust (i.e. the dip is steep NE).

The whole NW part of the Beartooth complex, from the N front E of Livingston to the S front near Gardiner has suffered deformation directed toward the SW, as in the N part of the Bighorn Mts. The S part of the Beartooth range is like the central Bighorns: deformed in a NE direction.

Further, the two large folds south of the Beartooth mts. (see below) have been deformed toward the SW, as have marginal folds of the S section of the Bighorns. Well shown by Rattlesnake-Cedar Mt. anticline (40,41) The NE limb shows miderate dips, the SW limb is vertical. Crest is broken by 2 strike faults. In the Pat O'Hara mt. anticline (42) both limbs are steep but the S limb is vertical.

Problems.

1. What kind of deformation would give an assymetric profile to a major uplift "but which impresses the same asymmetry on minor folds from one side of the major uplift to the other?

2. What is the direction of deformation producing this asymmetry reversed twice within the length of a single mt. axis, as in the Bighrons and possibly also in the Beartooths, i.e. overturning to the NE in the central section, to the SW N and S of it?

3. How do the crystallines in the core yield to make possible the sharp local folds in the basal Cambrian, and especially the local, lobe-like overthrusts?

Note on questions to follow: At (1,2), overthrusting is to NE; at (4,5) and (13-19), to the SW. The Beartooth range is overthrust to the E, NE on its E, NE sides (25-29); toward the SW near Gardiner (37-39). The Owl Creek mountains thrust to S on an E-W line at (43). The Cambrian shales and Ordov Bighorn dolomite are thrust several miles across the Chugwater formation. (Triassic). There is S thrusting also at (35), SW of Livingston.

Hence in this relatively small area there are overthrusts to the E, NE, SW, S. Which leads to the next questions:

4. What determines the direction in which overturning & overthrusting shall take place in a major uplift. In this region the dominant directions of major uplifts, anticlines, flexures and overthrust mt. borders are N25W, N20E, E-W.

5. In what way are these 3 directions introduced into the structural pattern? What is the origin of the straight borders and lines of flexure which are aligned in the ab ove directions?

6. What relation does the Gighorn basin bear to the surrounding ranges?

7. What relations do the minor anticlines and synclines in these basins especially along the borders of the Bighorn basin, bear to the structure an origin of the surrounding uplifts?

Heart Mt. Overthrust (44,46,47,49).: At 44 is a Klippe of Bighorn Ordov. ls, Missip. Madison ls., resting on folded Paleo and Eocene. W of this and other such remnants are large plates of the same ls lying as more or less horiz. thrust sheets on indepedently deformed or even horiz. younger seds (46). Largest thrust mass, (47,48,49). This area occupied by the thrust mass is equal to almost half the area of the S half of the Beartooth range. It inducates much greater thrusting thanon the borders of the Bighorn and Beartooth ranges. Minimum dustance of thrusting 28 mi. Such thrusts not unusual on the borders of intensely compressed folded mts

(For Heart Mt th rust see D.F.Hewett:The Heart Mt.Overthrust.JG 28(1920) 536-558; C.L.Dake: Heart Mt.Overtrust and Associated Structures in Park Co Wyo.JG 26(1918) 45-55).

There is no such folded mt.system here;the only possible area for this lies buried beneath the Tert.aggloms and flows between Sunlight Basin (50) & Yellowstone Lake.But the Paleo seds at (50) dip gently SW;at (51)the Cret.lies nearly flat;at (52),moderately folded Jur.,Lower Cret.The roots of this thrust or thrusts should be buried between (50,51,52);but the total space thus avaulable is little larger than the area now occupied by remnants of the thrust mass.

Intrusive ad Extrusive Igneous Rocks.:On the W side of the Bighorn basin the tectonic pattern has been greatly modified byintrusion and in large part concealed by a great thickness of aggloms and flows.The igneous history of such a region is closely connected with its tectonic history and must be read with it.In the Beartooth region are many parge and small intrusive bodies of acid porphyry. There are small sills and stocks in the Cambrian shales along the thrust zone on the E,NE fronts;also SE of (36) and at (37).The circular dome of Limestone Butte lies E of (34).There are sill-like bodies in the pre-Є granite alongsheeted zones.Bigger stock-like masses cut the pre-Є complex of the Beartooth mts.

1. What are the relations between the structural pattern of the Beartooths and these intrusions?

2. How are the times of intrusion related to the epochs of orogenic deformation?

3. What forces brought into existence and emplaced these magmas?

4. How do these intrusions compare in date and mode of placement with the Black Hills and Central Montana laccoliths?

The same problems apply to the intrusive masses that accompany the eruptive series of Yellowstone Park-Absaraoka Mt.region. W of (52) is a line of stocklike to laccolithic intrusions of qtz-diorite with NW trend.

5. What is the relation between orogenic deformations and the great volcanic activity which created the agglomerates and flows of Absaroka-Yellowstone Park region?

II General Chronologic Problems (Thom).

Specific Problems:

1. Have the Beartooth and Bighorn uplifts risen periodically during late Tert.amd Quat.?

2. Did "true orogenic deformation" in volving folding & faulting,take place as late as the Miocene?

3. May the later volcanic activity in Yellowstone Park be connected with such a compressive episode?

4. What are the time-space relations between the earlier eruptive activity in the Absaroka- Yellowstone area, the Heart Mt. thrust, and the "earlier pulses of compression which provided the uplifts encircling the Bighorn Basin?"

5. How were the Beartooth uplift porphyries produced; at what period or periods were they injected?

6. What was the time of the start of the Laramide? Much evidence supports the notion that local uplifts and basins were incipient during the Upper Cretaceous, "causing the formations to be thicker and of different lithology in present basin areas than above the exes of present uplifts". (Supratenous folding by which strata thinned above uplifts, thickened in basins might offer a different explanation).

Age of Structural Features along the Northwestern Margin of the Wind River Basin, Wyoming. J.D.Love. GSA Proc.1937,p.97.Abstract.

Major structure of the region is the Washakie Range,a series of folds arranged en echelon and overtruned and thrust in part NE,in part SW.These structures roughly parallel the axis of the Wind River Range,from which they are separated by a major syncline broken by an extneded zone of t thrust faults in which movement hasbeen to the SW.

Washakie structures result of at least 7 movements,started at close of Montanan and continuing in the early Cenozoic.Foci of movement shifted from time to time;intensity of deformation varied locally during each m movement. Summary of structural history:

1. Post-Montana-pre-Eocene: Folding,thrusting,normal faulting of the Washakie Range;central part thrust to NE and SW,eastern end thrust to the S,followed by extensive normal faulting.

2. Early Lower Eocene: ~~(Lower~~): Possible thrust sheet pushed 6 miles to SW,out into basin from E end of Washakie Range.

3. Close of early Lower Eocene: Folding along NE flank of Wind River Mts.

4. Close of late Lower Eocene:Development of thrust faults midway between Washakie and Wind River Ranges,parallel to latter,and thrust to SW.

5. Close of Middle Eocene:Folding in localized areas.

6. Close of Upper Eocene: Gentle folding in places along crest of Washakie Range.

7. Post-Oligocene: Folding and probably thrusting in localized areas along crest of Absaroka Range near Wiggins Peak,and possibly associated with intrusion of igneous rocks.

GEOLOGY ~~OF~~ ALONG THE SOUTHERN MARGIN OF THE ABSAROKA RANGE, WYOMING.

John David Love. GSA Special Paper 20,1939.

Partial Abstract.

Region includes S margin of Absaroka Range, Waskakie Range, W end of Owl Creek Mts., NW part of Wind River Basin.

Stratigraphy:

Tertiary:

Post Oliogocene? Caldwell Canyon Volcanics. Rhy, lat. flows, tuffs..... 300
Oligocene? Wiggins formation, andesitic aggloms, tuffs, flow 3000
Upper Eocene Tepee Trail form., basic andes. aggs, tuffs, flows, thin carbon. beds..... 2000
Middle Eocene. Aycross form. Clays, bentonite beds, acidic andesite tuffs, cgls..... 1000
Lower Eocene:
Wind River, red, white layered clays, ss..... 500
Indian Meadows, clays, ss, cse and fine cgls..... 1000
Cret.
Post-Frontier, undivided: soft maribe sh ss, few thin coal beds..... 1000
Frontier: Mainly ss, dk. marine sh, thin coal beds, white tuffs, these in lower part; upper part, soft gray shale. 550
Thermopolis-Mowry, undivided: Mowry: Hard slabby sh., T, soft black concretionary sh..... 600
Dakota group: Buff marine ss, gray to bl. soft marine shales..... 325
Jurassic:
Morrison: Siliceous clays, sh., ss, non-marine..... 400
Sundance: Marine gray sh., ls., ss, fossils..... 375
Triassic:
Chugwater:
Gypsum Spring member: Gypsum, some ls., sh..... 180
Popo Agie Member: Clays, ss, thin cgls..... 300
Crow Mt. " : Hard, soft, cliff ss..... 200
Red Peak member: Red sh and ss..... 500
Dinwoody: Slabby limy ss, sh, mainly marine..... 150
Permian: Phosphoria form. Ls, sh., ss, nodular cherts, marine, fossils plus..... 250
Penn. Tensleep: Hard cliff ss, some marine..... 275
Penn-Miss. Amsden: Sh., ls, chert beds, ss. Marine..... 200
Miss. Madison: Hard cliff fossi. marine ls..... 700
Devonian: Darby: Marin ls, sh., ss..... 150
Ordovician: Bighorn Formation:
Leigh member: fg dolomite..... 25
Massive dolomite member, cliffs..... 180
Lander ss member: fine marine ss..... 7
Cambrian:
Gallatin: Slabby marine ls, few sh..... 250
Gros Ventre: ls, lower, sh., ls, upper..... 600
Flathead: qtzites, ss..... 150

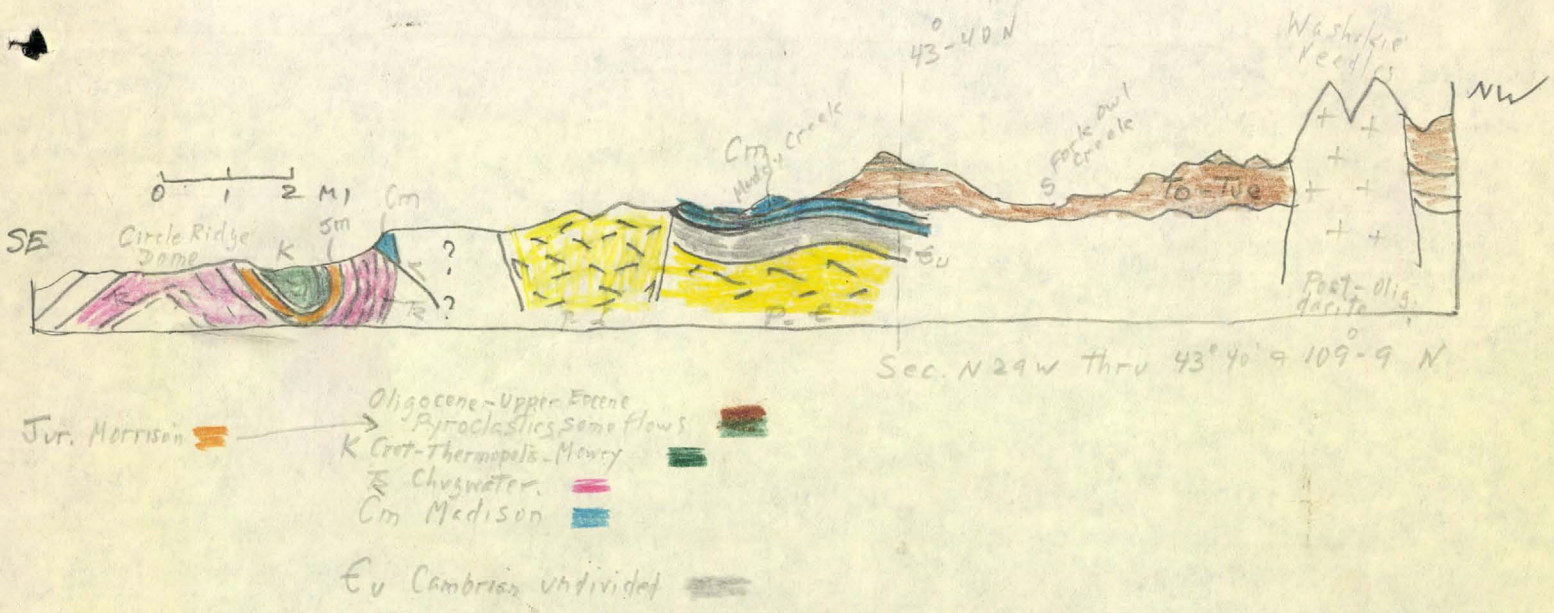
Pre-Cambrian: Core of Washakie and Owl Creek Ranges. Mainly coarse granite, granite gneiss. Basic rocks, schists. Some marble. But no thick seds as in Montana, Medecine Bow Mts. in SE Wyoming, or Uinta Mts.

Structure:

1. Owl Creek Mts.: Trend E-W, but range is series of en echelon folds, tremding N50° W. In places these minor folds & associated flts. extend completely across major uplift, W end range buried by Absaroka pyroclastics; range here an assymetric anticline, overturned and thrust-faulted along the southern flank (~~i.e. overturned toward S, and thrust to S. This thrrust is shown on the 1" = 40 mi. map).~~ On N flank of range Cambrian-Miss rocks folded into gentle flexures, most NW. N flank of range broad, gentle Madison ls. dip-slopes extend 10 miles NE of area.

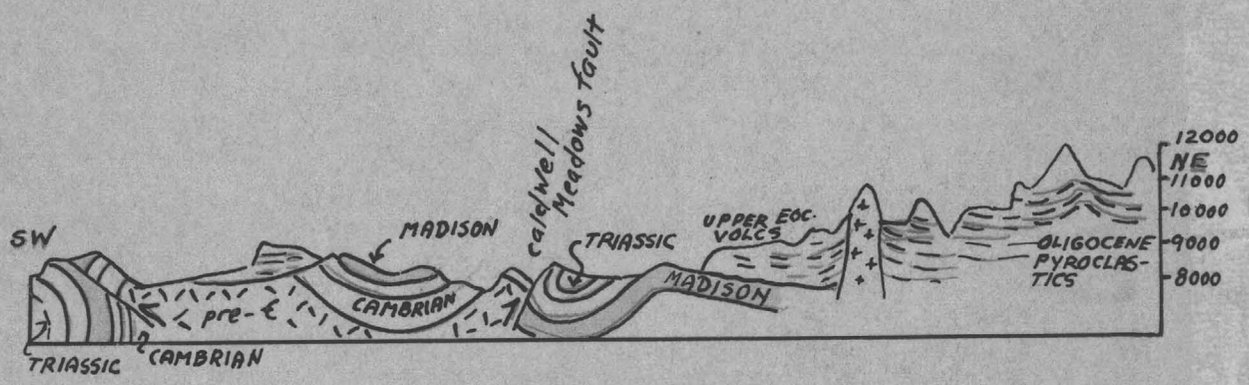
Along S flank of Owl Creek Mts. high angle reverse fault ~~xx~~ strikes E-W dips N, has placed pre-Ꞓ granite against overturned Madison ls. S of this fault is the ed Creek syncline, broad, pluges SE. Is the arbitrary structural boundary between Owl Creek Mts. on E, E-W, and Washakie Range, NW, on W.

Owl Creek Mts. just E of mapped area (which ends about W Long. 109° 09°, on the E). shows complex series folds and faults, mostly not shown on published geologic maps;

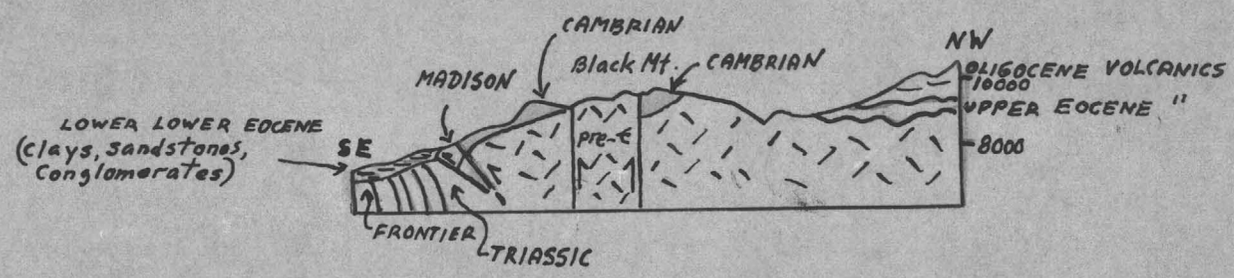


Darton's great arcuate thrust fault, at least 40 mi. long, concave to S, dipping S at 45° ends just E of the E bdry of the mapped area. Both ends are on the crest of the Owl Creek Range, but the main part of the fault cuts the northern flank. (S side up, aids uplift).

Just E of mapped area another high angle reverse faultdips steep N, trends E-W along S flank of Owl Mts. 9Synthetic fault along S flank).



SECTION 2 - WASHAKIE RANGE



SECTION 5 - WASHAKIE RANGE

SECTION 6 - OWL CREEK RANGE

STRUCTURE SECTIONS ACROSS WASHAKIE AND OWL CREEK RANGES, WYOMING

Generalized from J. D. Love: Geology along the Southern Margin of the Absaroka Range, Wyo. Geol. Soc. Am. Special Paper 20, 1939, Plate 16

0 1 2 MILES

2. Washakie Range: Structure same as that of Owl Creek Mts. General trend of range N65W, but subsidiary structures N10W. (Minor folds and faults) extending from outer flanks to pre-C core, possibly across entire uplift. Black Mt. just west of Red Creek syncline, is eastern end of range; its mass of pre-C and Paleo rocks is app. the SE end of a thrust block which moved to S and SW (Sect. 5, resembles left-central part of Sec. shown on my p.2: two aynthetic faults with uplifted block between, and a "thrust".) The thrust is called the Black Mt. thrust. Love calls the synthetic faults "normal" and ascribes them to the "caving in of a thrust block after compressive forces had been relieved" (p.92).

The Caldwell Meadows fault (Sec.2), a "high-angle reverse reverse fault" begins and ends in an asymmetric anticline overtruned to the NE. (Compare Section 2 with Plate IV-1B and -3, also -2; overturned anticlines go with the margins of diapir-like uplifts. See Solitario Dome, and Hebung-Spaltung-Vulkanismus).

p.92: "In Windy Gap.. a portion of another fault is exposed. It trends northwest... The plane is not visible but it apparently dips steeply. Local structures indicate strong compression, and it is assumed that this part of the fault is a high-angle reverse."

Washakie Range W of Wiggins Fork (about 109°35' W Long.) not mapped. N flank of Washakie Range exposed at Buffalo Fork Mt., wherethe major uplift trends E-W. St. John (F.V. Hayden: Report of Progress of Exploration in Idaho and Wyoming for the year 1877. USGS Terr., 11th A.R., 1879) showed Buffalo Fork Mt. to be an elongate dome with steep dips on the N, S, W; evidence of soythward thrusting along the southern flank. W and S of Buffalo Fork Mt. beds flatten out into broad synclines.

N. Fork Syncline: Between Washakie Range and Wind River uplift. Broad syncline, Ku exposed in center. Formed after close of Late Cret. and before beginning of Eocene. Low dips. At close of Early Eocene N45W series of f folds and faults developed along center of N Fork syncline, parallel to NE flank of Wind River Mts. Dip NE 35°. Folds limited to vicinity of faults; local overturing to SW.

Absaroka Range: Erosion r emnant of thick resistant Tert. deposits. Upper Eocene, Oligocene? and younger pyroclastic etc. rocks. Strata dip gently S, SE. Gentle warping, domes, anticlines. St. John thought Wiggins (Oligocene?) rocks, disturbed where they lap onto the Buffalo Fork anticline, had partaken to some extent in the upheaval which brought to view the Archean rocks in the Buffalo Fork quaquaversal".

Relation of Centers of Igneous Activity to Folds and Faults: In Wasakie Range, centers of igneous activity and all the exposed zones of intense folding and faulting are mutually exclusive. Nor large intrusions cut Paleo or Meso rocks; no intrusions seen anywhere in all the highly folded and faulted SW flank of Washakie Range.

Geologic History (Cret.-Tert.):

Pre-Laramide: Oldest Cret., Dakota, marine, marine-littoral, fg. ss, sh. Upper Cret. sea advanced over region, deposited Thermopolis sh. No break between this and Mowry but increasing abundance of volcanic ash. Probable source of volc. material in central Idaho. Beginning of Frontier, seas got shallower, several ss deposited. Coal beds, nonmarine coal swamps. Ash cont. thru Frontier. From close of Frontier to start of Mesaverde, fg. marine sh ss.

1. First Laramide Pulsation: See Nace: Summary of the late Cret. and early Tert stratigraphy of Wyo. Wyo Geol. Sur. Bull 26, 1936.

At close of Lance. Amount of folding, faulting, erosion not known; the pre-Cambrian core of the Washakie Range apparently exposed. That range and Owl Creek folded and probably faulted before dep. Fort Union to NE.

2. 3000 ft. of Fort Union Rocks deposited in Big Horn Basin. Granitic debris carried NE from Washakie Range.

3. Second Laramide pulsation at close of Fort Union. Intensity and extend of folding and faulting not known. During this and (1) major structures of Wsahakie range developed. In (3), additional faolding, fltg, along margins of Owl Creek and Wasahakie Ranges.

4. Deposition of 1000' lower Lower Eocene on a surface of high relief. Third pulsation thought to have occurred at this time, thrust sheet may have been pushed S into Wind River basin.

5. 4th pulsation caused gentle folding along NE flank of Wind River Mts. Lower Lower Eocene eroded in places. Broad Se trending valley formed between Wind River and Washakie ranges.

6. Deposition of 500 ft. upper Lower Eocene in above valley.

7. 5th pulsation: folding, thrusting along center of the syncline between Washakie and Wind River ranges.

8. Deposition of 1000' Middle Eocene; beginning of active Cenozoic vulcanism. Acid andesites, pyroclastics.

9. 6th pulsation: gentle localized folding. some rosion after close of Middle Eocene.

10. Deposition of 2000' of Upper Eocene. Vulcanism increased; basic andesites, basalts from local vents. Washakie, Owl Creek Ranges almost completely buried.

11. 7th pulsation: gentle localized folding, some erosion, close of Late Eocene.

12. 3000 ft. Oligocene? pyroclastics, plugs intruded, extrusion of flows, climax of Cenozoic vulcanism. Acid andesites. Washakie, Owl Creek ranges c completely buried; Wind River, Bighorn basins filled. Wind River, Big Horn ranges partly buried.

Note on volcanic vents (see above also): Upper Eocene? volcanic center just west of where pre-Cambrian core of Owl Creek Mts. is covered by Tepee Trail rocks (from Love's map, in core of uplift; intrusion with little doubt came up thru pre-C .) Other vents: north of Washakie range; at e ast end of that range, probably came up thru pre-C core, now buried there by volcanics.

13. 8th pulsation: folding in localized areas, recurrent uplift along parts of the buried Washakie range.

14. Intrusion of dacite plugs, extrusion of flows.

Epeirogenic uplift, Late Pliocene.

Discussion by C.Max Bauer, JG 48 (1940), 324-327.

Love's statement that "the Laramide Revolution was not a movement affecting all mountain ranges simultaneously" is not proven.

Central Wyo., Middle Rockies: throughout the Eocene and into early Oligocene forces causing folding and faulting were compressional with relatively little uplifting of the region. Fossils show mild climate, low elevation thuout Eocene. Such changes as occurred in Absaroka Mts. can be accounted for by piling up of 5000-6000 ft. volcanic debris.

After deposition of Oligocene White River forces causing deformation were "largely epirogenic or those causing upift and tension, in which normal faults predoninate. True, there were later local folds and possibly some reverse faulting, but this deformation followed the normal faulting of the Miocene and is assigned to later Tert. ~~Hence~~ therefore the Laramide may rev. well be closed with the Oligocene."

Note: Bucher et alii, Results of Structural Research Work in the Beartooth-Bighorn Region, Bull. AAPG 17(1933) p.689 state that the structural features of the region are products of basement block elevation rather than products of simple folding under tangential compression. Bauer gives them the latter origin; but the important point is that the structures shown on my Plate IV-1 are Laramide in the strict sense, whatever their origin.

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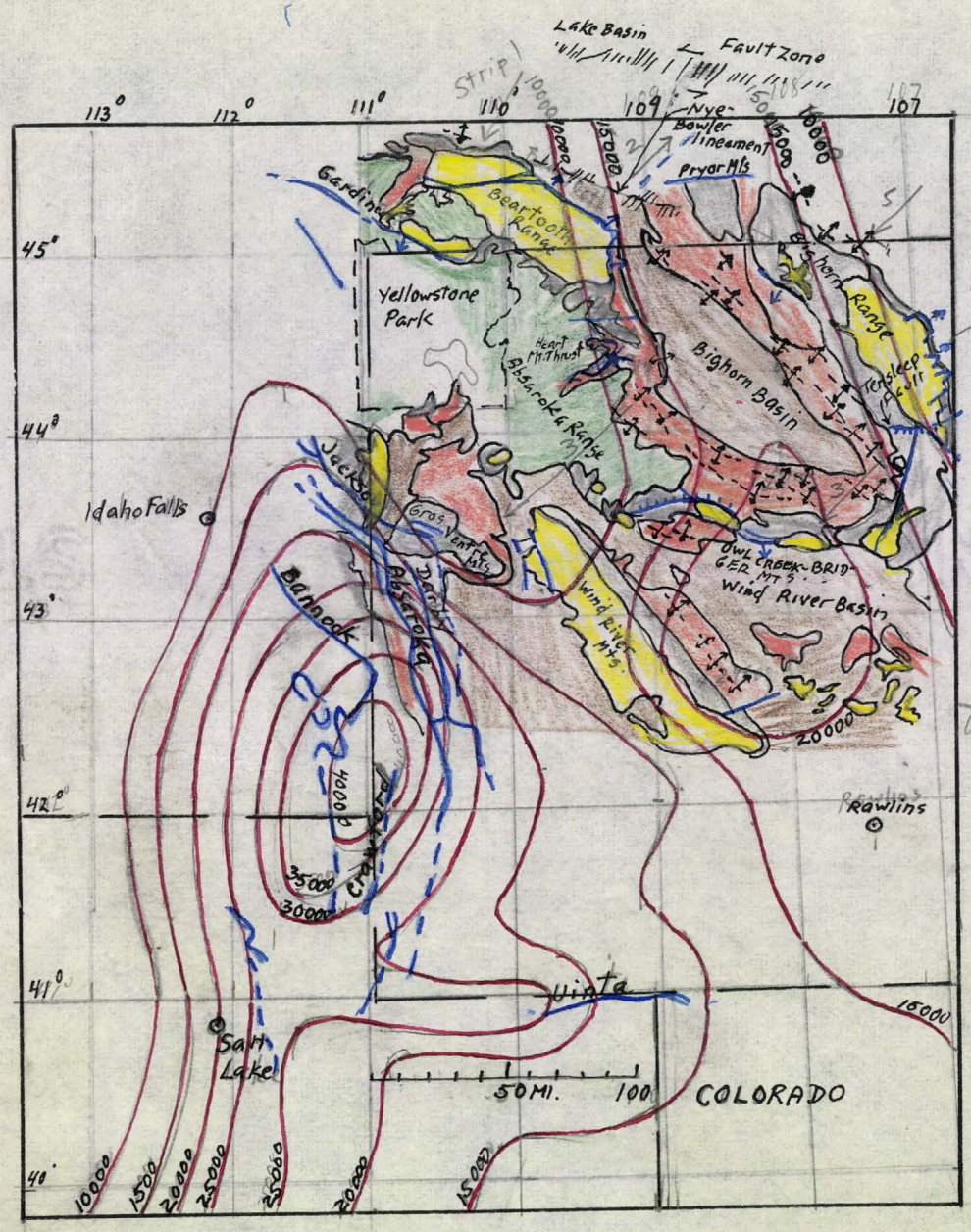
Reply by Love, J.G.49 (1941) 101-106. Bauer had stated that the main Tertiary plain of erosion and deposition was developed in the late Eocene and that epeirogenic uplift came after deposition of the Oligocene; that the Laramide reveolution closed with the Oligocene and that for the middle Rockies the Laramide close can be defined by an understanding of the forces effecting the deformation.

Love believes main Tertiary plain of erosion and deposition was developed after early Pliocene and that epeirogenic uplift took place probably in late Pliocene; and that close of Laramide not clearly defined, must be chosen arbitrarily. True that there were 2 types of movements in Tert. 1 orogenic; 2 epeirogenic. But if these typre are used as criteria for determining close of Laramide time of regional peneplanation or high-level pedimentation and the time of subsequent epeirogenic uplift must 1st be established. Love cites field data against the Eocene plain. The epeirogenic uplift could not have occurred before the high-level erosion and deposition surface was formed. Bauer claims this uplift began in early Miocene; Love refutes Bauer's evidence.

Well established that from time to time between Eocene and Pleistocene there were both compressional and tensional localized movements of various intensities in the region. See R.L.Nace: Summary of the Late Cret. and Early Tert. Stratigraphy of Wyo. Wyo.Geol.Survey Bull 26, 1936. Example: in SE Wyo; Laramide movements on E side Laramie range ended in Eocene, while in Saratoga Basin, 70 mi. W, they continued well into Pliocene. Bauer explains such instances by stating there were later local folds and possibly some reverse faulting, but this deformation followed the normal faulting of the Miocene and is assigned to the late Tert. NG because no evidence to show that most of the normal faulting is confined to the Miocene. Hence no

present basis for separating the late Tertiary localized compressional movements from the earlier movements of the same type. ~~Hence~~ Available evidence indicates that completion of the widespread plain and subsequent epeirogenic uplift occurred during or at the close of Pliocene.



Statistics of Minor Folds

Attitudes of which are shown on Chamberlin's Fig. 3

Long, gentle slope toward basin:	Steep slope toward basin:	Symmetric
39 (68%)	10 (17.6%)	8 (14.0%)

Asymmetric Folds:

(5 with gentle slope toward basin, 9
2 " steep " " "
Omitted because they lie on SW flank of Crazy Mt. Syncline or Powder River Basin - no data on NE sides)

	Gentle slope toward basin	Steep slope toward basin
On NE or N side of basin	16	6
On SW side of basin	18	2

Tertiary	Volcanics	Green
Tertiary	Sediments	Brown
Mesozoic		orange
Paleozoic		Gray
Pre-Cambrian		yellow

Diastrophic Behavior Around the Bighorn Basin.

R.T.Chamberlin, JG 48 (1940) 673-716.

Greatest thicknesses of Paleo & Meso formations occur as a N-S strip extending thru westernmost Wyo and E Idaho S into Utah. This long-lived geosyncline contains over 25,000 ft.of seds. It has several marked basins, one, centered at corner of Idaho, Utah, Wyo has over 40,000'.

E, Paleo & Meso seds thin fast, tho' irregularly, until only 10,000' in Beartooth-Bighorn region. Within this E platform region, as in the geosyncline, there are sinking basins which received more seds than nearby areas. This irreg.behavior presumably reflects influence of earlier structural developments.

In Cret.detritus from Western mts, formed in Idaho and Nevada and farther W continued to be added to the thick Paleo and Cret.in the geosyncline. Later Cret., approach toward geosynclinal conditions reached E to Beartooth-Bighorn region, previously an interior plateau area. Cret. strata here relatively thick, bringing total Paleo-Meso column up to 8000-15,000'. This thickness is still much less than that of the corresponding column farther W in the geosyncline.

Crustal activity progressed E; Laramide compression folded the thick, beds of the geosyncline proper into Appalachian anticlines and synclines, altho' individual ranges less contin, than in Appal. This folding accompanied by major overthrusting, especially where seds.exceptionally thick.

Just W of Wyo line and extending from Idao into Utah, Bannock overthrust (R.W.Ric hards and G.R.Mansfield: Bannock Overthrust: A Major Fault in SE Idaho and nE Utah/JG 20(1912), 681-707). Traced for 270 miles, horiz displacement more than 12 mi., possibly 35 (about 10% of the length). This thrust near deepest part of trough. Seds.on the westerly rise from the bo ttom of the trough were thrust E to the axial line. One easterly rise from bottom of syncline are the Crawford, Absaroka, Darby, Jackson etc. thrusts. Present traces of these do not follow exactly curvature of isopach lines, they show relationship to these, esp.in curving around the NE side of the pronounced deep mentioned. (See plan). Deep has had some influence on the faulting.

E of the geosyncline is the foreland area of Laramide orogeny. Thinner pre-Laramide strata, deformed differently. Pre-C crystalline complex now outcrops there over large areas. Paleo-Meso to west, folded and thrust geosyncline. When Laramide began basement of Beartooth-Bighron region lay within less than 15,000' of surface, and heneath large areas, 10,000'. Sed cover too thin a sheet to dominate and condition behavior of foreland in the deformation. Pre-C crystallines exerted decisive control in Bighorn-Beartooth-Wind River platform or foreland area. Predomiant uplifting of scattered oblong ranges and a sinking of basins. Crustal shortening only moderate.

Basins greater areally than uplifts, but the two opposing features developed togther: same orogenic manifestation. This studt primarily on Bighorn basin and its encircling ranges.

Bighorn-Beartooth Development: Uplifts around basin:Beartooth,Absaroka,Owl Creek-Bridger,Bighorn,Pryor,and the much feebler Nye-Bowler lineament. Larger such mt.units have sub units which developed with their own individuality. In Beartooth and Bighorn ranges there is a one-direction asymetry of structural features persistent in that segment but in the direction opposite from that of the adjoining segment on either side.

Reversal of Structural Symmetry:

Beartooth Range.

NW half of the main range consists of the N Snowy block and the S Snowy block; SE half,the Beartooth plateau,plus Rattlesnake Mt.appendage which continues the range to the SE. Three transverse segments.

(1) N and S Snowy blocks in the NW portion were uplifted most strongly on the SW;their thrusts dip NE. They are a NW transverse segment of the Beartooth range with SW overturning.

(2) Beartooth plateau block was uplifted most on its E and NE sides shows thrusting to E and NE.

(3) Rattlesnake Mt.block SE of the Beartooths shows SW overturning.

Absaroka Range.

Its Laramide structures largely concealed under Tert.volcs.;but the assymetric anticlines in the Bighorn basin alongside it have their steeper limbs on the SW. "Same probably true of Absaroka range";strengthened by fact that there is a line of isolated Paleo and pre-Є outcrops just within the W margin of the volcanic cover S of Yellowstone Lake,indicating strong uplift on the SW side of a range which was either the Laramide Absarokas or a continuation of the Wind River Mts.

Owl Creek-Bridger.

Unsymmetric,N slope gentler,steeper S slope with overthrust faulting outward from Bighorn Basin. (Toward the Wind River Basin-EW).

Bighorn.

Three segments of alternating symmetry. (1) S segment,which curves W to meet Bridger Range (suggests sagging of basin as the positive feature: cf.sagging hot water bag),was pushed up most on the SW (toward Wind River basin)and has the steep limbs of its minor folds in the same direction,continuing the strip of SW deformation around the S end of the Bighorn basin (and along the N side of the Wind River basin-EW).

(2) Central Bighorns most strongly uplifted on E"and thrust east-northeast toward the Powder River Basin" (p.680). (3) N Bighorns conditions again reversed.The OCs of pre-Є (structurally the highest portion of this broad segment) are near SW flank of range;bordering thrusts dipping under the range are along that margin. (4) In northernmost tip of the Bighorns the uplift lessens rapidly;here is a small structural plateau bounded by monoclines on each side (thrusts grading along strike to monoclines again);the monocline on the NE is slightly the greater.Considered with the more marked asymmetry of the near-by folds in the

Poder River Basin, northernmost Bighorns appear to belong to a tramsverse segment in which dominant surficial movement has been to NE. (reversal of direction shown by N Bighorns).

Chamberlin claims these directions of one-direction symmetry extend across basins, and divides the region into transverse strips of one direction symmetry. (See plan).

Strip 1: Two Snowy blocks of W Beartooths, with Crazy Mt. Basin on NE. Two Snowy boocks uplifted most on SW; S Snowy Bloack overthrust SW on Gardiner flt. (C.W. Wilson Jr.: Geology of the Thrust Fault near Gardiner, Mont. JG vol. 42 (1934) 649-663). On NE flank of N Snowy Mts. thrusting also SW up the gentle slope of the block or outward from Crazy Mt. basin.

Strip 2: SE half of Beartooth Range, Beartooth Plateua Block thrust strongly toward E, NE; near east front no minor folds in Bighorn Basin but in E half of basin anticlines have steep NE limbs, gentle SW limbs. Farther E, 4 major blocks of Pryor Mts. tipped up highest at their NE corners. Northernmost Bighorns "not far from s ymmetrical"; but folds in the Powder River Basin just E of the N tip of the Bighorns have steeper NE limbs, suggesting a further E continuation of Strip 2 in that latitude.

Strip 3: Shove to S. W. Rattlesnake Mt. SE appendage to Bighorns tilted up most strongly on SW and has in places been thrust SW along bordering th thrusts. Minor folds in W portion of Bighorn Basin facing Rattlesnake Mts. the Absaraoks and the Owl Creek-Bridger Range show turning toward the SW away from the Bighorn Basin. (Normal condition according to my notions). Owl Creek Bridger Range mainly very unsymmtrical, gentle dips on N slope steep on S. Wind River canyon thru Owl Creeks, low angle thrust brings Cambrian onto steeply inclined Trias. rkc. (J.R. Fanshawe: ~~Geology~~ Structural Geology of the Wind River Canyon Area, Wyo. Bull. AAPG 23 (1939) 1439-1492). Central section of Owl Creek range more symmetrical. Granite area bounded on both sides by faults.

Southern Bighorns pushed up most on the SW; same true for nearby anticlines in Powder River Basin, and those around S end of Bighorn Basin. (Normal condition for Powder River Basin). Asymmetry in same SW direction continues the strip SW across Wind River Basin and holds for Wind River ~~(Exl. Baker~~: Range and Gros Ventre Range beyond. This is the longest and largest of the strips.

Strip 4: Symmetry again reversed in central Bighorns, highest part of range. W side Paleozoics gentle dips; E flank nearly vert., thrust NE. Folds in nearby part of Bighorn basin overturned to NE (normal). In Powder River Basin in front of E thrusts of Bighorns little minor folds "as if the ~~mt~~ mt. thrusts had here sufficed to take up the crustal shortening." Thrusting in Strip 4 to NE.

Strip 5: N Bighorns reversed from Central, thrust SW; anticlines turned that way in both Powder River and Bighorn Basins. But this strip does extend far into Bighron Basin (~~i.e. there is one such abnormal fold, see plan~~). Farther SW out in the basin folds turned the other way. ("thrust" NE, i.e. with long slope of folds toward basin, the normal attitude. Chamberlin cuts off Strip 5 SE of northern Bighorns, to include one anomolous minor fold, long slope toward NE. SW of this all folds "normal".) Chamberlin makes a point that the area in front of a strongly

overthrust mt.front (E of Central Bighorns,E of SE Beartooths) lacks minor folds;apparently upward and outward escape of the rocks relieves the stress in front of it. (This sounds OK:according to my notions,where the edge of an uplift is a sharp flexure,flow of material down the sides, meeting resistance at the bottom of the basin,is likely to result in wrinkling,buckling;but where these "thrusts",which I believe to be synthetic uplift faults rotated by flow of material down the flanks occur,flow or movement of mater al down the flanks is both by flow and by "thrusting" along the synthetic fault plane,occuring simultaneously. The "thrust" displacement would obviate the need of buckling. With a synthetic fault being rotated by flow,there is no call for movement along the fault plane to cease,in fact so long as the upward shove of the block being uplifted continues,movement must continue along the vertical part of the synthetic fault,and if so,along the flattened,rotated continuation of that segment of the fault.)

Boundaries between Strips of Opposite Symmetry.

Boundaries between strips of opposite symmetry drawn from assymetry of anticlines & uplifts.Are there structures which coincide with these boundaries? Adjustment between belts could have been by (1) by differential horiz.movement concentrated along single fault or zone of fltg.(2) by bending of the rocks in a shift zone;(3) by gradual accomodation thru a moderately wide intermediate zone;(4) some combination of these.

On Ranges: Tensleep fault,main transverse fault of Bighorns,boundary fault between Strips 3,4.Upthrow on N,as much as 1200 ft. Fault plane nearly vert.,mostly dips S.Strong drag along fault "normal","but reversal of drag along one short section of it inicates later reversal of slip movement and suggests later compression,"(p.685). C.W.Wilson Jr.:The Tensleep Fault,Johnson & Washakie Cos.,Wyo.JG 46 (1938) 868-881) thinks undercrowding of the S unit against the N side has caused a turning of the fault surface to give a N dip of 85°."An overcrowding of the high-standing central Bighorn segment against the lower southern Boghorn segment would also produce the observed turning " (p.685). Getting close to home here.

Notes from Wilson's paper:Associated but unbroken monocline is W continuation of Tensleep fault,traced 5 miles W of W end of fault. General structural pattern of Bighorns suggests that a system or old structural lines in basement complex influenced the yielding to stresses of Laramide rev. Suggested that"even the crustal blocks,delimited by these preexisting structural lines,were uplifted as a composite unit,each block neverheless moved separately,being tilted in a different direction and being crowded against the adjoining blocks along the separting fractures..The tilting of these blocks resulted in the development of sharp,monclinal flexures or thrust faults along the uplifted edges of the "trapdoors" as the mantling sediments were draped over the basement rocks. A compressive stresses became more intense,the uplifted edges of these tilted "ramplike" blocks were crowded over adjoinig lower parts of adjacent blocks and locally pushed out,or thrust, over the nearly flat-lying strata of the surrounding plains." (p.873-874).

Tensleep fault separates Central Bighorns,overthrust E front,gentle W flank,from S Bighorns,steep or overthrust W front,gentle E limb.

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Wilson has reason to think Tensleep fault formed early in Laramide and that the thrust on the W side of the "Horn", S of the Tensleep's E extremity, was related to it in time but continued to function longer. "As brought out in other publications, the early phase of the Laramide orogeny was dominantly differential uplifting of the ranges, whereas horizontal shrusting became more important in the later phase." (Fits my mechanics). (p.685).

In the Basins: No faults between strips seen. Nye-Bowler lineament shows horizontal shifting by the en echelone faults. See C.W. Wilson Jr., Geology of the Nye-Bowler Lineament...Bull. AAPG 20 (1936) 1161-1188. En echelone faults thought to have resulted from tearing of surficial seds. by horiz. movement on a long deep-seated fault or shift-zone. S side E. S Pryors have been more tipped at their NE corners and more strongly thrust NE than the N Pryors, which are on N side of E prolongation of the N-B lineament. See D.L. Blackstone Jr.: Structure of the Pryor Mts., Mont. JG 48 (1940) 590-618.

Types of Block Behavior:

A. Where Mountain Subunit slopes gently toward adjoining basin: Pn backslope of an uplifted range Paleo and Meso seds have minor folds toward toward crest of range (normal attitude). Where thrusts develop from splitting of such folds the thrusts dip away from the range. In riding up the slope the upper beds have moved more than the lower ones (I say just the reverse, material moved down the slope; and C has to explain transmission of forces thru weak seds; I do not. My thrust dipping away from the range become underthrusts, but this is an especially likely place for underthrusts-easiest relief toward bottom of basin.) This well shown on N slope of N Snowy ~~Range~~ block of Beartooth Range, SW of Living-
See E.C.H. Lammers: Structural Geologt of the Livingston Peak Area, JG 45 (1937), 268-295. Here splitting of anticlines in a succession of slice faults was well advanced before deformation ended. p.689 "Not only were the sedimentary rocks urged ~~urged~~ up the slope of underlying crystalline rocks of the North Snowy block, but the pre-Cambrian rocks were also involved in the slice faulting. The conclusion seems justified that the slope between basin and upwarp was a more decisive factor in governing the structures than the differences between sedimentary of crystalline rocks."

(The main surface of discontinuity would be the pre-C surface, and the seds would tend to slide down this, from with an uplift toward the S. The shearing stress generated by this sliding might set up complementary shear planes in the seds (attribute of flow) These would rotate clockwise and end with rather steep attitudes, which is probably what these thrusts have.

B. Where steep side of mt. subunit faces a basin. Steep sides of the mt. blocks vary from (a) simple flexures with high angle faults (some Pryor blocks) (b) overtruned anticlinal limbs and overthrusts in various stages of development (2 of the Beartooth blocks; Central Bighorns; Owl Creek Range).

Intermediate stages: Rattlesnake Mt., Five Springs Section of Bighorn and SE Pryor block are IM stages. (Note admitted transition from flexures with steep faults to thrusts). In (a) horiz. yielding has been least relative to uplifting; (b), the horiz. compression has been more effective, and the early upbowing has given suffiecient relief and steepness of slope between the uplifted block and the adjoining basin for the basin margin, under further compression, to be forced under the edge of the mt. block and the latter to bulge out above as an overturned anticline (fetish of tangential compression). With still further compression (refer to Bain, Flow folding) the overturned limb of this fold has split along a part of the mt. front, and the upper part has moved out toward the basin on one or more thrust faults. Mt. block sjows squeezing in below, flaring out above. p. 690: The bordering thrust faults vary from ordinary reverse faults with moderate slip where the bulging above was not great to low-angle overthrusts with notable horizontal displacement where a hreater rotational st strain developed (a hard rock geologist). Great difference in elevation and a steep slope between the basin and the range have been important factors in causing the low-angle faulting."

Low-angle thrusts best developed where two conditions met: (1) mountain block is one of the most strongly uplifted ones of the region as shown by esp. large area pre-Є outcropping (Beartooth, Central Bighorn) (2) margin of the uplifted block pronounedly convex toward basin (NE front Beartooth plateau block, NE side central Bighorn block). In each case highest part of range is near the faulted margin. p. 690: "The basin immediately in front is deep toward the range and one may observe also that relatively few minor anticlines are to be seen in this part of the basin."

(Shows relation of thrusting to uplift; arcuate form, convex toward basin is connected with the limited strike-length of these overturned synthetic faults: upward movement greatest at a mid-point, dies out either way; the greater the uplift, the greater the "thrusting" and overturning by flow. To overturn such a fault requires smooth uninterrupted flow of the beds whereas formation of fold wrinkles occurs when top of a bent-down plate is wrinkled, crowded. Fold wrinkles are probably much less common in relative basins, oppisute positive uplift such as that herein described, than in sagging basins. This suggests Bighorn Basin a true sag, possibly previously an uplift: many minor folds on either flank).

Where the convex bend is esp. pronounced transverse tear faults developed. Here, as at E corner of Beartooth plateau block, the overriding portion of the mt. mass, as it spread out in an arc of increasing circumference, developed tension concentric with its arcuate front; radial, vert. tear faults developed. See E.L. Perry: Flaws and Tear Faults. Am. Jnl. Sci. 29 (1935) 112-124. As displacement on the thrust continued, there was differential horiz. movement along the vert. tear faults, some sections advancing further than others. (Beartooth plateau and Central Bighorn Blocks).

With Gardner thrust uplift of South Snowy Mts. behind it was great, but curvature of margin only moderate. Less displacement on fault than along Be Beartooth plateau front, fault steepr.

Adjustment around the corner of a block: Best shown on NW corner, N Snowy block of Beartooth Range. Gentler slope of this tilted block faces NE "With surficial movement from the basin on the north the sedimentary beds have been crowded up this slope, forming assymmetrical folds and thrust faults along which southwestward overriding has taken place." Block itself, lifted high at an early stage, acted as a superficial buttress confronting this movement.

Around NW corner of the butress and in the much lower terrain farther west the SW shove of the s eds ~~xxxx~~ prgressively less impeded by butt ress. So folds and faults curved around the corner and advanced farther S in this oower country than up slopes of buttess, forming arcs/Where S advance was greatest, low angle thrusts. See D.C. Skeels: Structural Geology of the Tail Creek-Canyon Mt. Area, Mont. JG 47(1939)816-840.)

Narrow Zones of Folding & En Echelon Faulting: Nye-Bowler Lineament, Lake Basin Zone, Cat Creek Anticline. For Lake Basin see R.T. Chamberlin: A peculiar belt of oblique faulting. JG 27(1919)602-613. Faults steep, tension. S block movee E relative to N block. robably above steep fault in basement This deep-seated fault much older than Laramide: locus of differential crustal movement in Paleo.

Nye-Bowler Lineament (C.W. Wilson Jr.: Geology of the Nye-Bowler lineamen Bull. AAPG 20 (1936)1161-1188) similar. Outbreak of lavas and ejectamenta along W part of this line of weakness thought to mark very early stage of Laramide (Judith River times). p.694: "Also relatively early, when strong vertical movements caused uplifting of the range and sinking of the Bighorn basin, a monoclinal fold developed over the basement fault". At W end (Beartooth Range) and E end (Pryor Mts.) high side of fold on S in conformity with nearby uplifts. But in much longer middle portion across Bighorn basin high side on N, because basin which w as sinking lay mostly to S. Difference in elev. here enough to cause accumulation of thickseds on S side, thin on N. Later lateral moevment made tearing en echelon faults. S side E. In later Fort Union times (Tongue River stage) older monoclinal fold as arched, given its local anticlines and domes.

The Minor Folds: Most conspicuous on flanks of ranges and the sides of the basins. Constant trend over whole region, N30-60W, ave. 45. (prevailing).

INFERRED NATURE OF THE MAJOR PROCESSES.

All Leith, geosynclinal theory, gigantic strain ellipsoids etc.

Thrust Faulting at the South End of the Big Horn Mountains, Wyo.
J.D.Love. Bull. GSA 51, Nos. 10-12, Abstracts, 1940, p.1934.

There are several thrusts (sic) along the E and W flanks of the folded (sic) Big Horn Mountains, but only nromal (sic) have been previously described from the south end of the Range.

The following data are from SW of Badwater P.O. They suggest that the S margin of the range was thrust south on to the Wind River Basin; upper Eocene beds cover the actual fault zone.

1. Over 2000 ft. of upper Cret. fine-grained shale and thins ss strking E-W are overturned to the south along Badwater Creek.

2. There is not room for the normal section in the covered area between the south-dipping Lower Paleozic beds on the S end of the range and the overtruned Upper Cretaceous strata directly to the south.

3. The overtruned Cretacesous strata are unconformably overlain by more than 500 ft. of Paleocene or lower Eocene boulder beds containing angular masses of Paleo ls. to 30 ft. diam., IB with coarse ss. Near mts these strata dip 35° S, but flatten rapidly basinward and become finer-grained.

4. The mt. front and the Tertiary strata S of it are cut by many normal faults, some of which are post-Eocene. These faults suggest collapse of a thrust block.

Discovery (?) of thrust faulting here necessitates complete revision of previous interpretations of the geologic history, both of the S part of the Big Horn Range and the NE part of the Wind River Basin.