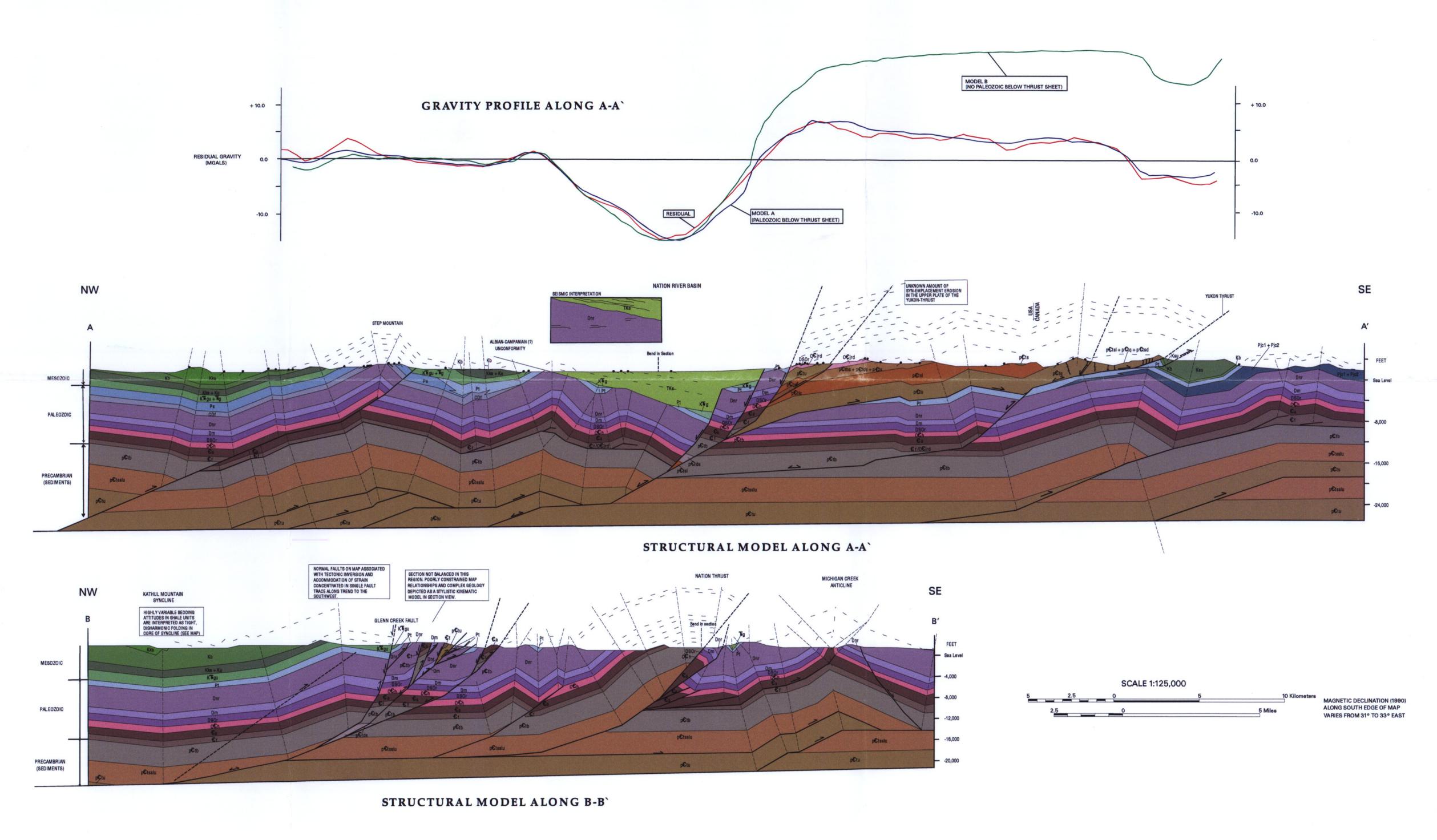
## ALASKA DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS IN COOPERATION WITH ARCO ALASKA, INC., AND DOYON, LIMITED



### SUMMARY OF STRUCTURAL MODELS OF THE NATION RIVER BASIN AREA by Robert F. Swenson and Paul H. Daggett

The complex structural geometries produced by polyphase deformation in the Nation River Basin area, have resulted in many different ideas for proposed geologic histories (e.g. Howell and others, 1990 and Dover, 1992). The hypothesis presented in this report will provide an alternative model for the exposed geology of the region.

## GENERAL CHRONOLOGY

Structures within the Nation River basin and surrounding area suggest at least two distinct orogenic events from middle Cretaceous to the present. Previous deformational phases produced relatively minor structural features (for example, Triassic/Cretaceous angular unconformity). The geologic map of the area shows a complicated system of contractional and tensional structures which range in scale from small, fault-related folds to major allochthonous thrust sheets that are overprinted by a similarly trending suite of normal faults.

Howell and others (1990) suggest that the first influx of syntectonic coarse clastics in Valanginian time indicates the onset of Mesozoic contractional deformation, possibly related to the emplacement of the Tozitna terrane to the north of the Glenn Creek fault. They also relate the thermal maturity of the Paleozoic rocks to the thickness of the Cretaceous foreland basin deposits. These deposits were in turn overridden by structural nappes produced during the emplacement of the allochthonous terrane to the northwest which provided the thermal regime necessary to create values seen in thermal indicators at the surface today. The timing of this structural duplexing is not clear, nor how it relates to the later tensional system.

The main difference between this study and Howell and others (1990) is that they do not interpret the extensional faults as part of a separate divergent structural event. They suggest the prominent TKs basins of the area are either piggy-back or foreland type and are all related to the contractional regime. Howell and others (1990) concluded that drag-fold deformation of TKs rocks near the Tintina fault suggests that all TKs deposition, and therefore contractional deformation, was

Our interpretation of more recent mapping suggest the prominent normal faults (1) truncate and apparently offset the contractional structures; (2) appear to be kinematically related to the development of the Nation River basin; and (3) are the result of transpressional stresses related to motion along the Tintina fault. These features suggest that two distinct phases of contractional deformation (Late Jurassic to Early Cretaceous north-vergent, and Late Cretaceous east-vergent) resulted in a distinct trend variation between structures in the region. The entire system was later redeformed by extensional deformation kinematically linked to dextral motion on the Tintina fault during latest Cretaceous to Tertiary time.

This study makes the following conclusions: (1) Contractional deformation within the study area is predominantly the result of a Late Cretaceous compressional orogenic phase. (2) This Late Cretaceous contractional deformation, that emplaced the Yukon Thrust, is a distinct and separate deformational system from the younger tensional regime which created the An important piece of evidence for these conclusions is the abrupt change in thermal maturities across the unconformity at the base of the Nation River basin. Recent geochemical data (ARCO; the University of Missouri) indicate that basal TKs sediments show relatively little thermal alteration whereas strata as young as Early Cretaceous below the unconformity have R. values of 2.4 percent (dry gas window). The high thermal maturities suggest that strata beneath the unconformity were structurally buried, thermally altered, and subsequently uplifted and

## STRUCTURAL TRANSECTS

unroofed prior to the development of the Nation River basin.

Structural models A-A' and B-B' depict the geology along trends parallel to the transport direction (orthogonal to structural trend) of both the tensional and contractional regimes. Kink-band fold geometries are an artifact of the structural balancing software used and may or may not mimic the observed style of folding. More concentric type folding could be accomplished by the addition of more dip domains but would not dramatically change the overall interpretations. Mapped surface geology was the primary constraint for preliminary subsurface interpretations, which was then integrated with gravity interpretations and limited seismic data to produce the final sections. Unit thicknesses were determined where map control was best and then held constant laterally.

The following assumptions and guidelines were used in the structural

1. Overall stratigraphic thickness to basement is assumed to be constant along the models; however, the thickness of individual horizons can and does vary. The thickness of the units in cross-section view is held constant locally and does not always coincide well with apparent thicknesses shown on the map. This is mainly the result of poorly constrained field relationships and lack of subsurface data. Lateral facies changes within a unit are held to a minimum for structural modeling.

2. Metamorphic/crystalline(?) basement remains relatively consistent in both regional dip and coherency throughout the

3. The contact between the Tindir Group and basement acts as a regional decollement for deep-seated thrusts exposed in the region. Other decollements occur throughout the stratigraphic column, but are minor in comparison.

4. With the exception of tight parasitic folding in some of

the more shale-dominated units, all the major structures exposed at the surface are geometrically related to subsurface features (that is, no major structural disharmony exists). Unless clearly documented by present structural geometries, any younger-over-older fault relationship indicates tensional tectonics rather than a more complicated contractional history. 6. Simplified structural models were used in areas of complex, poorly constrained geology (model B-B', east of the Glenn Creek fault). Depiction of the geology here is to show extensional reactivation of the thrust system to produce alternating younger over older/older over younger fault relationships. No attempt

was made to show kinematic history.

## DISCUSSION

## Extensional Structures

Exposures along model B-B' provide an analog for the early developmental stages of the more evolved extensional structures depicted in model A-A'. For example, a synthetic series of normal faults exposed east of the Glenn Creek fault (model B-B') are superimposed on original overthrust structures exposed along trend to the southwest (Precambrian over Cretaceous). This polyphase fault sequence produces a linear map pattern of alternating younger and older fault blocks and is considered to be a less developed analog to the fault system that created the Nation River basin (compare model B-B', and model A-A'). Due to poor stratigraphic control and the complex nature of structural relationships, a more simplified depiction of the geology in cross-section view was used in the structural models to help with understanding of the models.

Another important aspect of the extensional fault system is an apparent area-wide kinematic relationship. The complex fault patterns to the west and south of the Nation River basin are interpreted as a transfer zone of tensional strain between the single, high-displacement fault trace exposed to the southwest and the westward-dipping controlling fault(s) (model A-A) beneath the Nation River basin, that is, an en echelon fault transfer zone. The lack of TKs sediments in the Glenn Creek fault area indicates that either: (1) the degree of extensional displacement across the transfer zone does not remain constant; (2) more recent deformation, which is recorded in the TKs strata of the Nation River basin, uplifted and eroded those rocks; (3) motion on the Glenn Creek fault did not create a depositional basin; or (4) some combination of 1, 2, and 3.

## Contractional vs. Extensional Structures

Although structures created by the tensional system indicate a consistent kinematic relationship, that same relationship does not hold between the contractional and tensional systems. The subparallel nature and apparent lateral merging of the normal fault and thrust fault traces in the Glenn Creek area implies a geometric relationship, but does not necessitate kinematic linking. An alternative interpretation is that the normal faults are localized at or near original overthrust structures and were somewhat controlled by those early geometries and zones of weakness.

On model B-B', this apparent geometric relationship is interpreted as reactivation of thrust fault planes that were advantageously oriented within the later, tensional stress field and tensional strain could then take advantage of preexisting steep fault planes (i.e., thrust ramps). In the Glenn Creek area, for example, where all compressional stress is taken up on a single coherent thrust, the tensional stress is similarly accommodated by a single normal fault. Conversely, where many steep reverse-fault imbricates resulted from the shortening phase, a complicated sequence of synthetic normal faults developed

The eastern margin of the Nation River basin is another example of tensional reactivation of a thrust fault ramp. Extensional structures exposed along this margin indicate that under the deepest part of the Nation River basin along model A-A', reactivation of the steep fault

ramp that emplaced the Yukon thrust sheet appears to have concentrated tensional stress. This resulted in the localization of normal faults and created the asymmetric geometry of the basin with the deep axis located over the old thrust ramp. This interpretation suggests that any interrelationship between the contractional and extensional structures in

## Contractional Structures

Although the contractional system has been overprinted by the tensional system, excellent examples of the various phases of shortening can still be observed. An analogy for the initial phases of Yukon Thrust translation is best seen where model B-B' crosses the Nation Thrust. This structure shows a deep-rooted thrust translating Precambrian hanging-wall strata up a relatively steep ramp. Continued shortening would have placed a relatively coherent thrust sheet over a nearly complete Phanerozoic section, doubling the entire sequence, as seen in the Yukon Thrust. Retrodeformation of the Yukon thrust sheet to the point where the Precambrian hanging wall cutoff coincides with the upper ramping portion of the thrust, located near the eastern edge of the Nation River basin, would show a very similar geometry to what is presently observed on model B-B'.

An important difference between the geometries depicted in the two models is the lack of footwall deformation in model A-A'. The folding seen in model B-B' indicates a dramatic amount of strain is contained within the footwall and is apparently related to ramping of the main fault. Similar footwall deformation is most likely the case beneath the Yukon Thrust, but because of the lack of any sub-thrust constraints, this deformation was not depicted in model A-A'. Subthrust deformation could be documented only where it directly affected the hanging-wall strata as seen in the hanging-wall anticline near the U.S./Canada Border. Although no direct measurements can be made to determine the age of the sub-thrust stratigraphy, indirect measurements have been made to help constrain sub-thrust models.

## INTERPRETATION OF STRATA BENEATH THE YUKON THRUST SHEET

A previous interpretation of the geology in the Nation River area (Dover, 1992) shows many of the structural complexities exposed in this region, but does not completely address sub-thrust structure and stratigraphy. We believe that our mapping and interpretaion of exposed geology, in combination with gravity and structural modeling, strongly suggests Paleozoic rocks underlie nearly the entire Yukon Thrust sheet. The following factors are evidence for Paleozoic rocks under the Yukon thrust sheet: (1) Erosional reentrants into the hanging-wall, both north and south, show Paleozoic strata far westward in the footwall; (2) Hangingwall geometries indicate a major footwall ramp that parallels the southeastern margin of the Nation River basin; (3) Structures in the Glenn Creek area are formed of similar early-phase geometries as discussed above; and (4) a promising correlation exists between calculated gravity using the present structural interpretations and the observed gravity along the

the Nation River basin area is geometrical and not kinematic.

same model (see red and blue curves above model A-A).

If the Yukon Thrust footwall region is composed of collapsed ramp imbricates of the Tindir Group, the observed residual gravity curve should match the Precambrian model curve above model A-A'.

New density measurements taken on 1100 samples throughout the region

stratigraphy. Based on the measurements, the cross-section interpretation

along section A-A' and the modeled gravity response was compared with

The red curve (see gravity profile above) is the residual gravity anomaly

gravity response from a model based on the geologic cross section where

(model A). The green curve is the calculated gravity response from a model

(model B). Over the Yukon Thrust sheet, there is an excellent match between

Paleozoic rocks are interpreted to occur beneath the Yukon Thrust sheet

the residual gravity anomaly and model A's gravity response. Model B's

gravity response is about 16 m Gal greater than the residual gravity anomaly

over the thrust sheet. Therefore, the gravity modeling indicates that lower

density rocks occur beneath the Yukon Thrust sheet which is additional

evidence for the presence of subthrust Paleozoic stratigraphy.

where only Precambrian rocks occur beneath the Yukon Thrust sheet

along model A-A' taken from sheet 1. The blue curve is the calculated

show a significant contrast between Paleozoic and Precambrian rocks.

This contrast can be used to test various hypotheses for sub-thrust

(2.72 gm cm<sup>3</sup>). End member density models were then constructed

was simplified into bodies of Tertiary (2.35 gm cm 3), Cretaceous

(2.56 gm cm<sup>3</sup>), Paleozoic (2.6 gm cm<sup>3</sup>), and Precambrian rock

the residual gravity anomaly observed.

## CONCLUSION Structures within the Nation River Basin area indicate that post-Early Cretaceous deformation was dominated by two distinct orogenies.

Although the systems appear to be kinematically related, recent data indicate the relationship is merely geometric and the result of reactivation of preexisting structures. The early contractional system created structures ranging from small fault-related folds to allochthonous thrust sheets, and the tensional system produced a series of overprinting, en echelon extensional structures. In more highly evolved areas, the extensional faults produced depositional basins that were subsequently deformed and partially eroded. Continued clarification of the structural style and history will be crucial for further development of geologic models in this region.

SEISMIC WALK-THRU PROFILE

The present structural geometries and end-member structural/gravity models indicate that: (1) the Yukon Thrust has a similar, but more advanced kinematic history than the Nation Thrust, and (2) the footwall region contains a nearly complete section of Paleozoic stratigraphy.

## **ACKNOWLEDGMENTS**

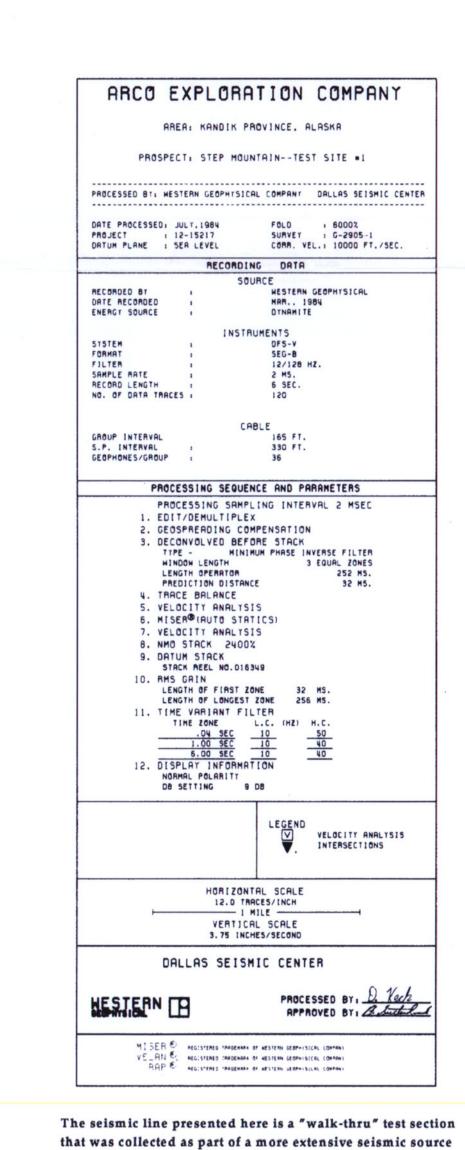
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## REFERENCES CITED

Brabb, E.E., and Churkin, M., Jr., 1969, Geologic map of the Charley River Quadrangle, East-Central Alaska; U.S. Geological Survey Miscellaneous Investigations Map I-573, scale 1:250,000, 1 sheet.

Dover, J.H., 1992, Geologic map and fold and thrust belt interpretation of the south eastern part of the Charley River quadrangle, east-central Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-1942, scale 1:100,000, 2 sheets.

Howell, D.G., Johnsson, M.J., Underwood, M.B., Huafu, L., and Hillhouse, J.W., 1990, Tectonic evolution of the Kandik region, east-central Alaska; preliminary interpretations: in Bradley, D.C., and Ford, A.B. (eds.), Geologic studies in Alaska by the U.S. Geological Survey: Geological Survey Bulletin, (USA) 1992, p. 127-140,



and receiver testing program conducted during the winter season of 1983-1984. This line is the only seismic profile collected by ARCO in the area. The CDP fold ranges from 1 on either end of the line to 60 in the middle.

## 1:250,000, 1 sheet.

Van Kooten, G.K., Watts, A.B., Coogan, J., Mount, V.S., Swenson,

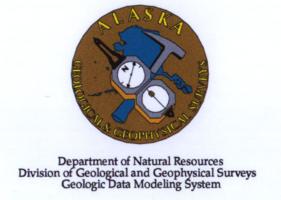
R.F., Daggett, P.H., Clough, J.G., Roberts, C.T., and Bergman,

Yukon Territory, Canada, Report of Investigations 96-6c,

Alaska Division of Geological & Geophysical Surveys, scale

S.C., 1996, Gravity Maps of the Kandik Area, Alaska and Adjacent

# GEOLOGIC INVESTIGATIONS OF THE KANDIK AREA, ALASKA AND ADJACENT YUKON TERRITORY, CANADA



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