Dr. Whitham - for his collection.

THE SEISMOTECTONICS OF SOUTH-CENTRAL SASKATCHEWAN

By

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SEISMOLOGICAL SERVICE OF CANADA

INTERNAL REPORT 76-3

Division of Seismology and Geothermal Studies

Earth Physics Branch

Department of Energy, Mines and Resources

April 1976

Excellent
Talk to MJB
① - publication of note? - after field expt
② - revn 1, 2, 3, 4 - what is likely.
KW.

A Summary of Seismic Activity

Two minor earthquakes were recently felt at Radville, Saskatchewan, about 100 km south of Regina. These were very rare events in view of our knowledge of the seismic history of southern Saskatchewan. Only six earthquakes are known or thought to have occurred in this region to the present time. These events are listed in Table 1 and plotted in Fig. 1.

The largest earthquake occurred on May 15, 1909. Its magnitude was estimated to be $5\frac{1}{2}$ (Horner et al. 1973). The epicentre was not determined instrumentally but on the basis of intensity information (Heck and Eppley 1958). A reassesment of the limited data availabe for the event, especially in light of subsequent seismicity, suggested an epicentre in southern Saskatchewan, northeastern Montana or northwestern North Dakota with maximum intensity VI near the epicentre and perceptible to distances of 550 km from the epicentre (Horner et al. 1973). Figure 2 is an isoseismal map of the 1909 earthquake compiled by O. Nuttli of Saint Louis University (per communication).

The remaining seismicity consists of five events between 1968 and 1976, the largest of these having magnitude m_n 3.7 on July 26, 1972. It is significant to note that prior to the mid - 1960's and the development of the Canadian Seismograph Network earthquakes less than about magnitude 4 could not have been detected in central Canada. As the network exists today the location capability in southern Saskatchewan is possibly as low as magnitude $2\frac{1}{2}$.

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TABLE 1

SOUTHERN SASKATCHEWAN EARTHQUAKES

EVENT NO.	DATE	H-TIME	MAGNITUDE	LATITUDE	LONGITUDE
1	May 15, 1909	9:15 PM MST	m_b 5½	50° ± N	105° ± W
2	Sep 11, 1968	12:00:06 GMT	m_n 2.7	49° 15' N	108° 08' W
3	Oct 11, 1968	12:28:04 GMT	m_n 2.9	49° 37' N	104° 29' W
4	Jul 26, 1972	03:58:19 GMT	m_n 3.7	49° 21' N	104° 56' W
5	Mar 23, 1976	22:31:47 GMT	m_n 3.2	49° 34' N	104° 19' W
6	Mar 25, 1976	00:12:17 GMT	m_n 3.5	49° 23' N	104° 15' W

The 1972 earthquake near Bengough, about 125 km south of Regina, was felt to distances of 30 km from the epicentre with a maximum intensity of IV (Fig. 3, from Horner et al. 1973, Fig. 1). The focal depth was estimated to be less than 10 km. Speculation immediately following this event suggested that it could have been the result of a solution cavity collapse (see the next section). An analysis of the observed surface waves did not support a collapse mechanism but was consistent with a vertical strike slip fault striking approximately N30^{o} E. Note that the isoseismals drawn for the 1909 earthquake (Fig. 2) appear elongated in a northeast-southwest direction.

The 1976 earthquakes near Radville, about 100 km south of Regina, were slightly smaller than the Bengough event but were similar in terms of their apparently small radii of perceptibility and relatively high maximum intensities. The first event on March 23 was magnitude m_n 3.2. From telephone conversations with newspaper editors in Radville, Weyburn and Gravelbourg it appears that the shock was felt only in Radville including, perhaps, a small area surrounding the town. The shock was felt by everyone in the town (1200 population, 4000 to 5000 people within a 20 mile radius). People were frightened and ran into the streets. There were reports of cracked walls, fallen plaster and buildings that moved ½ inch off their foundations. The administrator of the Radville hospital reported 15 cracks in hospital walls including an eight-inch opening in a solid concrete wall (Saskatoon Star Phoenix, March 25, 1976). It was also reported that all (?) the books in the school library were knocked off their shelves and that two water pipe connections were broken. This intensity information would suggest a maximum intensity of about VI and the small radius of perceptibility would suggest a shallow focal depth, similar to the Bengough event.

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The second Radville earthquake on March 25 was slightly larger than the first, with magnitude m_n 3.5. Very little information has been obtained on intensities produced by this event except it was not felt as strongly in Radville as the first event on March 23. Note in Table I that the calculated epicentres of these two events are separated by about 20 km. In terms of true accuracy the separation may be of the order of 20 ± 20 km. In view of the apparant small radius of perceptibility of the first event a shift of 20 km in the location of the second event might explain why it was not felt as strongly in Radville even though its magnitude was slightly larger. In the appendix all the newspaper accounts received to date are given. The newspaper in Radville, Weyburn and Gravelbourg have all run stories asking their readers to send us their accounts of these two events. At present, no replies have been received.

The two earthquakes of 1968 (Table I) were not reported felt. They were both less than magnitude 3. Note the coincidence of the epicentres of the October 11, 1968, event and the recent Radville event of March 23, 1976.

Tectonics of Southern Saskatchewan

South-central Saskatchewan is underlain by a moderately thick sedimentary section consisting, in general, of Mesozoic clastics overlying competent Paleozoic carbonates. The Precambrian basement, at a depth of 5,000 feet (~1500 m) under Regina, dips to the south to a depth of 9,000 feet (~2700 m) under the Saskatchewan United States border. A general stratigraphic column by DeMille et al. (1964, Fig. 2) is shown in Fig. 4. Of particular interest is the Middle Devonian Prairie formation which consists largely of salt and lesser anhydrite beds. In southern Saskatchewan these beds reach maximum thicknesses of 670 feet (~200 meters).

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The Regina-Hummingbird trough is a structural low in the sedimentary section of south-central Saskatchewan. It is interpreted as being the result of large-scale subsurface leaching of Devonian salt beds and collapse of the overlying strata. This is illustratred in Figures 5 and 6 (from De Mille et al. Figs. 7 and 8, resp.). The Regina-Hummingbird trough runs approximately south from Regina to the United-States broder. In Fig. 7 (from Christopher et al. 1971, Fig. 23) the instrumentally determined epicentres are plotted. They show a strong correlation with the boundries of this trough.

De Mille et al. (1964) suggest basement movement fracturing the sedimentary section to create permeability and permit the fluid movements necessary for salt leaching. This movement is infered from the association of the magnetic and gravity anomalies of the Nemo-Estes trend that extends north from the Black Hills of North Dakota with the Regina-Hummingbird trough. This is illustrated in Fig. 8 (from De Mille et al. 1964, Fig. 9). Christopher et al. (1971) also suggest movement of basement lineaments as control on the general linearity of the solution channels and the intermittency of salt removal.

These views are supported by the study of Alabi et al. (1975) in which they trace an anomaly in the magnetic variation fields from the Wollaston Lake Fold Belt in the Churchill Province of Saskatchewan south to the Black Hills uplift and the northern end of the Southern Rockies. The location of the "North America Central Plains conductivity anomaly" is shown in Fig. 9 (from Alabi et al. 1975, Fig. 3). They suggest this anomaly could represent a major continental fracture zone roughly 1800 km in length. This zone coincides exactly with the Regina-Hummingbird trough in south-central Saskatchewan as well as with four of the five instrumentally located earthquake epicentres.

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There is a strong correlation between observed seismicity, collapse structure and an inferred fracture zone in the Precambrian basement in south-central Saskatchewan. The vertical strike-slip mechanism proposed for the 1972 Bengough earthquake indicated that event was not a solution cavity collapse. One possible and obvious conclusion is that movement along the basement structure is responsible for the seismicity as well as providing control on the solution channels and salt removal. Another possible mechanism for the seismicity, as suggested by Baar (pers. commun.), is tensional faulting in the sedimentary sequence above the Precambrian basement. This is caused by overburden pressure on competent cap formations over solution cavities. Until reliable fault-plane solutions and focal depths are obtained the question of mechanism will have to remain open.

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Conclusions

1. Five earthquakes have been instrumentally located in southern Saskatchewan between 1968 and 1976. All had magnitudes less than 4. The Bengough earthquake in 1972 and the two events near Radville in 1976 were strongly felt over small areas of perceptibility. The first of the Radville earthquakes was reported to have caused slight damage.

2. Prior to the mid-1960's and the development of the Canadian Seismograph Network earthquakes less than about magnitude 4 could not have been located in central Canada. An earthquake widely felt over the Prairies and north-central United States in 1909 with an estimated magnitude of $5\frac{1}{2}$ was believed to have occurred in the vicinity of south-central Saskatchewan. The maximum intensity was VI and slight damage was reported.

3. A strong correlation exists between observed seismicity, areas of salt removal and associated collapse structures, and an inferred fracture zone in the Precambrian basement in south-central Saskatchewan. The seismicity is probably not due to cavity collapse. The question of whether the seismicity is due to movement in the basement structure or tensional faulting in the sediments or some other mechanism will have to remain open until accurate hypocentre and fault-plane solutions are obtained.

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Recommendations for Further Study

1. Contingent on further seismicity in southern Saskatchewan similar to the events near Radville or Bengough, the Division should consider conducting an immediate intensity and aftershock survey. The need for such a survey is indicated by the apparant damage attributed to the first of the Radville earthquakes on March 23, 1976. With respect to the recent seismicity near Radville, the Division should consider further investigations into the extent of the purported damage. If the possibility exists perhaps someone from the Division could make a short stop-over in Radville in conjunction with another trip. The interest created by these recent events in southern Saskatchewan would also make a visit by someone from the Division very useful for purposes of public relations.

2. Strong consideration should be given to installing a regional seismograph station in southern Saskatchewan. It would monitor any low-level continuing seismicity as well as provide badly needed control on the depth and location of larger events. At present the closest seismograph station, SES, is some 450 to 500 km from the epicentral region.

3. The Division should consider conducting a detailed reflection/refraction survey over the epicentral region. The sedimentary structure under southern Saskatchewan appears to be well known from numerous well data; however, little is known of structure in the basement and crust. The inference of a basement fracture zone from magnetic and gravity data could be confirmed by such a survey. It is my understanding the Division is now trying to find a major University consortium experiment in this area next year.

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4. Consideration should be given to the idea of conducting a regional seismicity survey in south-central Saskatchewan. This project could be planned for about a month's duration using two people and five or six smokers. The instruments should probably be deployed around Radville and Bengough in the hope of detecting and accurately locating any minor activity. Focal depth determinations would indicate whether the events were either in the sediments or the basement. A survey such as this could be conducted in conjunction with the forementioned reflection/ refraction experiment.

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Appendix

This section contains all newspaper clippings received to date concerning the Radville earthquakes of March 23 and 25, 1976.

THE RADVILLE STAR

Vol. 65 No. 13
SUBSCRIPTION - $6.00 PER YEAR
Thursday, March 25th, 1976

With news coverage for a large area in Southern Saskatchewan

Earthquake in Radville?

Residents of Radville were a bit shook up Tuesday afternoon when two earth tremors (the worst ever felt in this area) literally rocked and moved buildings in this town.

People on main street were seen running out of the business places on to the streets and their have been some reports of cracked walls and plaster falling from ceilings.

It was reported that some of the buildings were moved as much as half an inch of the foundations.

It is not known at this time how large an area was effected by the tremors, although some farmers south of Radville experienced the same sensations as in town.

THE RADVILLE STAR

Vol. 65 - No. 14
SUBSCRIPTION - $6.00 PER YEAR
Thursday, April 1st, 1976

With news coverage for a large area in Southern Saskatchewan

Earthquakes confirmed . . .

Quakes measure 3.1 and 3.5 on Richter Scale

Earth tremors shake locals

A minor earth tremor hit the Town of Radville last Tuesday, March 23rd at approximately 4:30 p.m. and this was followed by another tremor at 6:30 p.m. the following evening.

The Star spoke with Bob Horner, Seismology Division, Department of Energy, Mines and Resources, Ottawa and he informed us that the magnitude of the minor quakes measured 3.1 and 3.5 respectively, on the Richter scale.

This is only the second quake that has been recorded officially in the province of Saskatchewan, with the first one being at Bengough in the year 1972 measuring 3.7.

Unofficially, there was an earth tremor that shook the province in 1909 with an intensity of 5.5.

The conversation in this town for the best part of last week centered around earth tremors and reports of objects falling off shelves, cracked walls and ceilings, people running into the streets, were common.

Prof. Kanasenich of the University of Alberta's physics department cautioned against any alarm, because earthquakes of this size are not dangerous.

the effects . . .

. . . the faces of hospital staff were whiter than their uniforms, according to Ivan Stinson, hospital administrator.

. . . she said she heard a big bang and then merchandise started falling off shelves - Giselle Bourassa, an employee of Carles Red and White.

. . . everyone was running into the streets to see what had happened - Mrs. Agnes Prost, Radville.

Saskatoon.
Star Phoenix March 25/75

tails, saying
"slightly higher" than the eigh

Star Phoenix March 25/76

Mild tremor damages buildings in Radville

It could be a day or two before a mild earthquake at Radville is confirmed.

A tremor hit the community of 1,200 Tuesday afternoon. No one was injured, but the tremor caused minor structural damage to the town's hospital and high school.

E.R. Kanasewich, a geophysicist with the University of Alberta physics department said Wednesday he is checking with federal seismic stations at Suffield Alta., and Flin Flon, Man., to confirm the reading.

"We have a very small earthquake or tremor recorded at 4:33 p.m. CST at about the distance of Radville or Bengough."

The quake registered 3.3 on the open ended Riechter scale, barely above background noise levels, Kanasewich said.

Ivan Stinson, administrator of the Radville hospital, said he felt a, "little bit of a shake," followed by, "one hell of a boom," when he was in the hospital.

"It then felt like someone was standing behind me and gave my chair a quick jerk. The whole building shook," he said.

Investigation following the tremor revealed about 15 cracks in hospital walls, including an eight-inch opening in a solid concrete wall, he said.

Kanasewich said the area near Bengough was last hit by a 3.9 to 4 magnitude quake July 26, 1972. The depth of that earthquake was shallow, less than 6 miles, and he believed this tremor might have been as shallow.

While it is not known what geological structures are beneath the earth's surface near Radville a magnetic irregularity was mapped in the area during 1974-75. It showed that the crystalline basement rock, thousands of feet below the surface, had a lower resistance to electrical currents than surrounding rock.

In 1909 a large earthquake, estimated at 5.5 on the scale, hit the area.

Stinson said he was sure that the noise he heard was not a peal of thunder.

Radville is about 30 miles southeast of Weyburn.

—GETCHELL

GRAVELBOURG Star

Volume 43 No. 15 Gravelbourg, Saskatchewan April 1, 1976

EARTHQUAKES REGISTERED IN RADVILLE

by Bruce Pitfield.

RADVILLE: Two earthquakes sent tremors through the Radville, Saskatchewan area and left tremors with many of its residents last Tuesday and Wednesday afternoons.

According to Bob Horner, Earth Physics Branch, Department of Energy, Mines & Resources, in Ottawa, "the second earthquake was a bit bigger than the first" which registered 3.1 on the Richter scale.

Dr. E. R. Kanasewich, from the Department of Physics at the University of Alberta, in Edmonton told The Star that "the rough location of the first quake was north by northeast of Radville about ten miles or closer." At the time of this writing (March 29, 1976), "there was no exact location for the second earthquake but it appears to be close to the first," Dr. Kanasewich stated. This first quake took place on Tuesday, March 23, at 4:30 p.m. C.S.T. while the second quake announced itself at 6:10 p.m. C.S.T. on Wednesday, March 24. Waves from these quakes were "felt as far east as (the province of) Quebec," said Dr. Kanasewich. He went on to explain that last week's earthquakes were close to the earthquake epicentre that took place in 1968.

On July 26, 1972 an earthquake was located quite close to Bengough, Saskatchewan.

Mr. Horner -- when commenting on the 1972 Bengough earthquake -- told The Star that some people from the University of Regina thought ground water was circulating through underground salt formations causing them to collapse. However, the Department of Energy, Mines & Resources proved this theory to be incorrect.

One of the problems confronting seismologists (personnel involved with the scientific study of earthquakes and their causes and results) in their studies of earthquakes is that "before 1965 we never had any seismographs in Canada that could measure below magnitude 4.5 - 4.0 so there could have been many (earthquakes)," stated Mr. Horner.

The two earthquakes at Radville last week were monitored by seismographs in: Suffield, Alberta; Flin Flon, Manitoba; and Thunder Bay, Ontario, according to Mr. Horner.

The Star spoke with Ain Raitsaks, Officer-In-charge of Lakehead University's Seismic Station in Thunder Bay, Ontario, on Tuesday afternoon.

Mr. Raitsaks (pronounced ray-sacks) stated "I picked up three blasts on the 24th of March. The second blast arrived one-half hour after the initial one and the third came 18 minutes after the second." Thunder Bay time was one hour ahead of Saskatchewan time. He continued to explain that the seismographic stations in: Flin Flon & Churchill, Manitoba; Suffield & Edmonton, Alberta; Penticton, B.C.; Yellowknife and Baker Lake in the Northwest Territories send in recordings to Ottawa. There is also a seismographic station in Victoria, B.C., which acts as a type of clearing house for recorded earthquakes in Western Canada.

Mrs. Dave Chouinard who lives on a farm 7 miles west of Radville told The Star in a telephone interview this past Monday that "most of the damage was inside the school and the hospital." She continued, to say that no one was hurt as far as she knew.

Mr. Horner stated that on or about May 15, 1909 an earthquake took place in southern Saskatchewan that measured 5.5 on the Richter Scale. The epicentre of that quake centered near the border of northeast Montana and northwest North Dakota. "In those days," said Mr. Horner, "there were no seismograph stations or very few if any" and, thus, much information had to be retrieved from United States' stations.

Both Mr. Horner and Dr. Kanasewich request anyone with pictorial and written information to send the data to either one of the following addresses: Dr. E. R. Kanasewich, Dept. of Physics, University of Alberta, Edmonton, Alberta.; Mr. Bob Horner, Earth Physics Branch, Dept. of Energy, Mines & Resources, 1 Observatory Crescent, Ottawa. Ontario K1A 0E4.

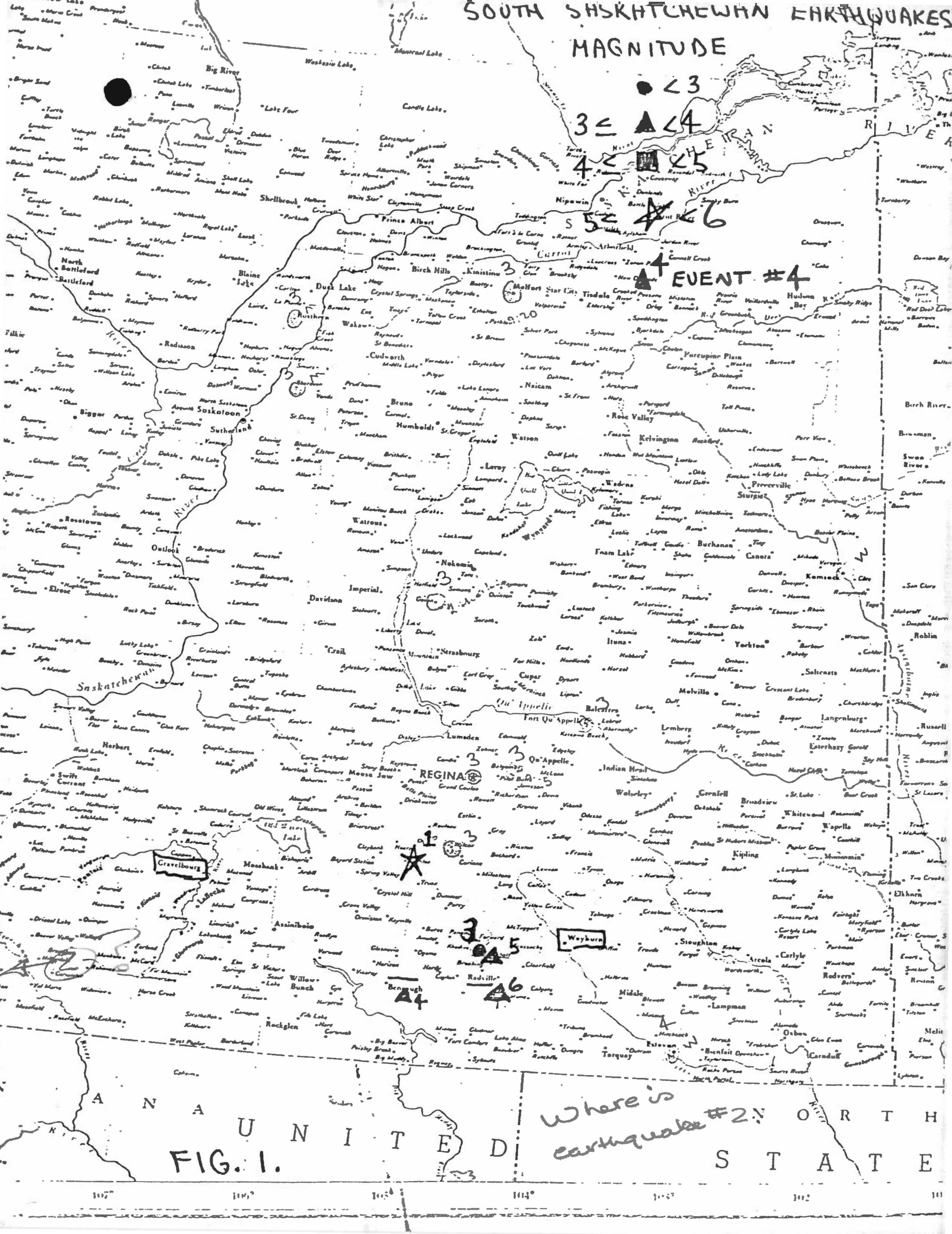
SOUTH SASKATCHEWAN EARTHQUAKES
MAGNITUDE
● <3
3 ≤ ▲ <4
4 ≤ ■ <5
5 ≤ ✱ <6
EVENT #4
Where is earthquake #2?
Prince Albert
Saskatoon
REGINA
Moose Jaw
Weyburn
Gravelbourg
Yorkton
Melville
Estevan
Humboldt
Nipawin
Melfort
Outlook
Watrous
Fort Qu'Appelle
Indian Head
Assiniboia
Radville
Bengough
Saskatchewan
Qu'Appelle
Carrot
River
UNITED STATES
NORTH
CANADA

FIG. 1.

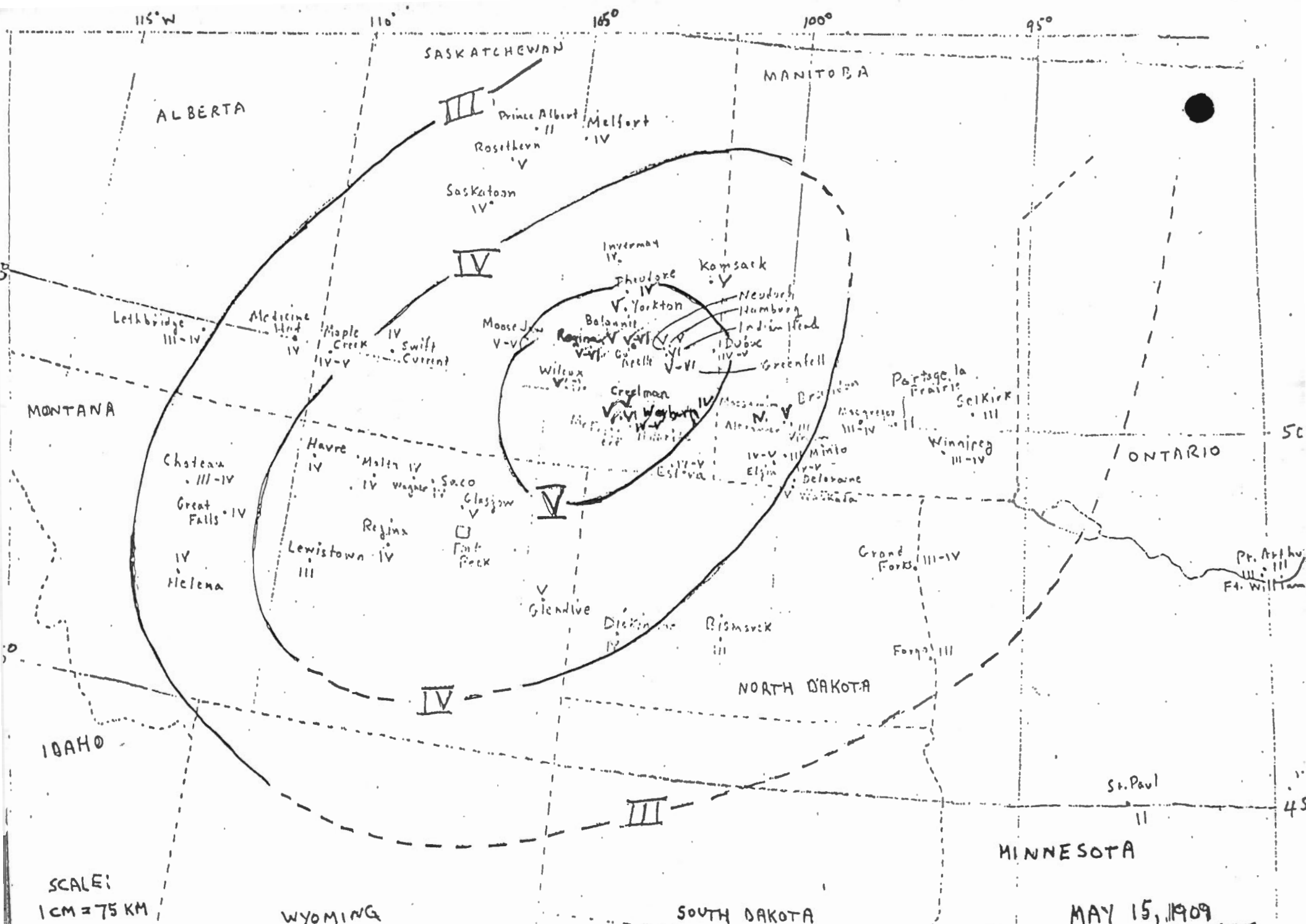

FIG. 2. Isoseismal map of the May 15, 1909 earthquake (compiled by O. Nuttli)

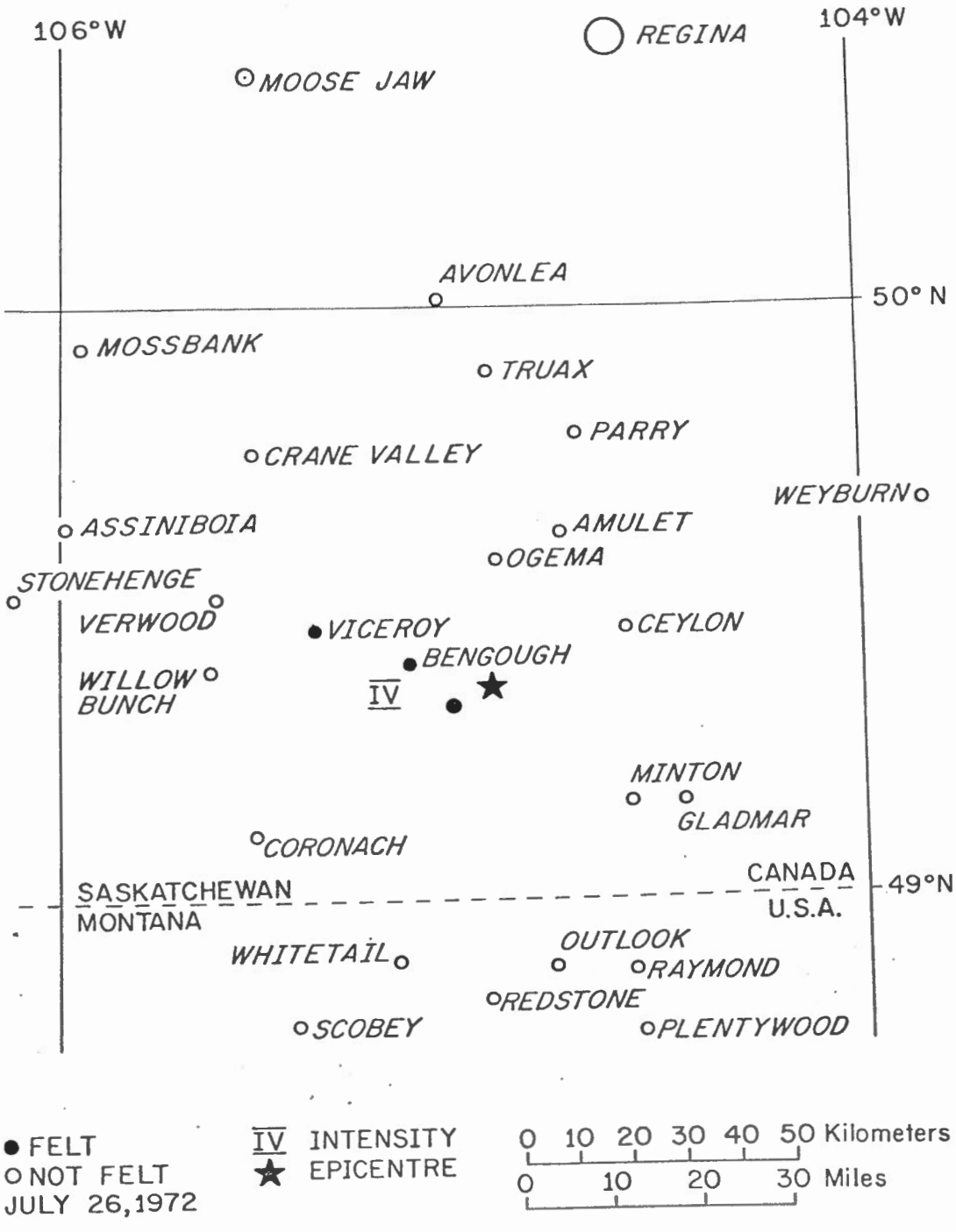

Fig 3. Intensities produced by the Bengough, Saskatchewan, earthquake of July 26, 1972

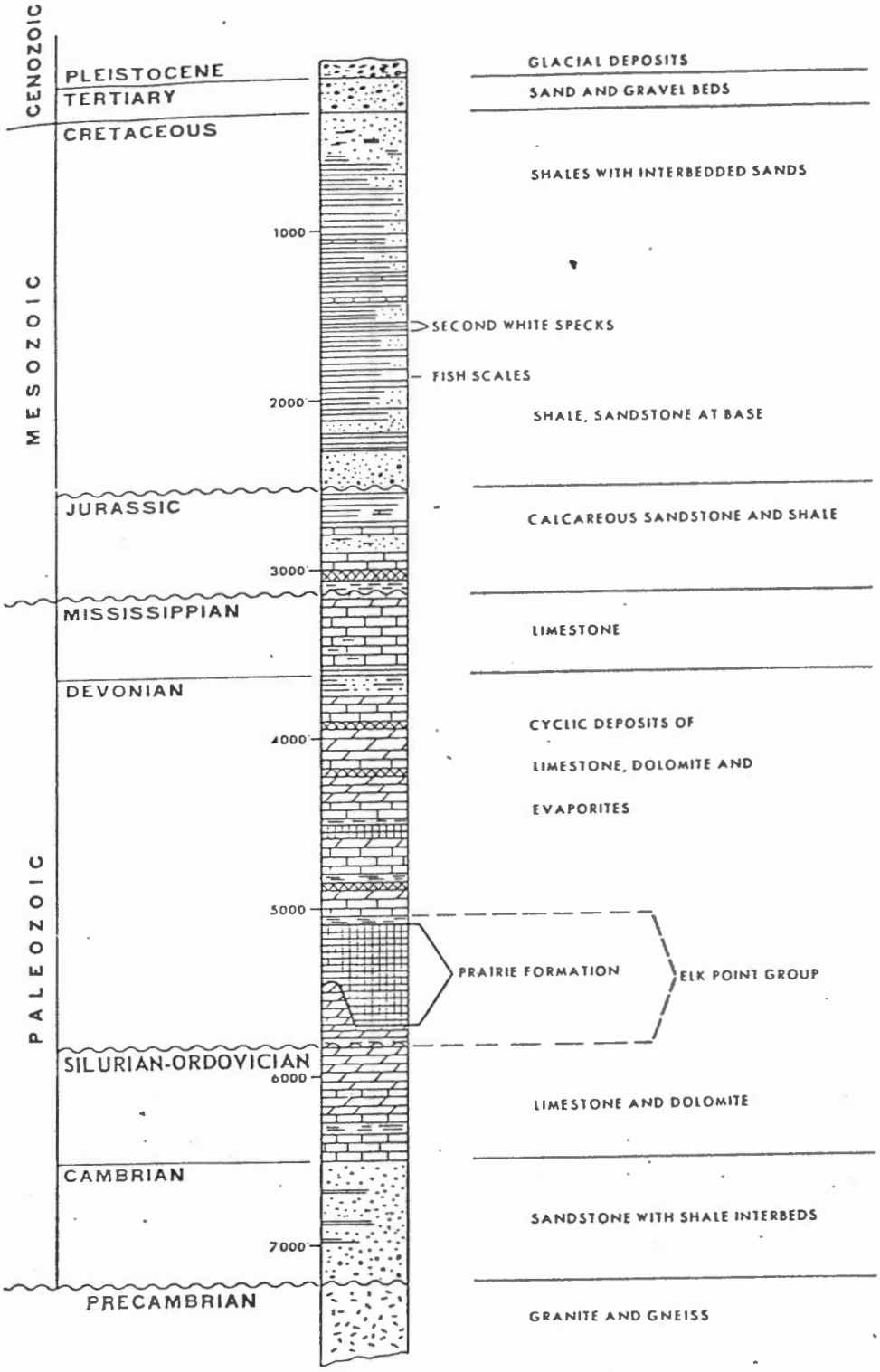

Figure 2. General stratigraphic column showing position of the Prairie evaporites in the subsurface of southern Saskatchewan

Fig: 4. (Deville et al. 1964)

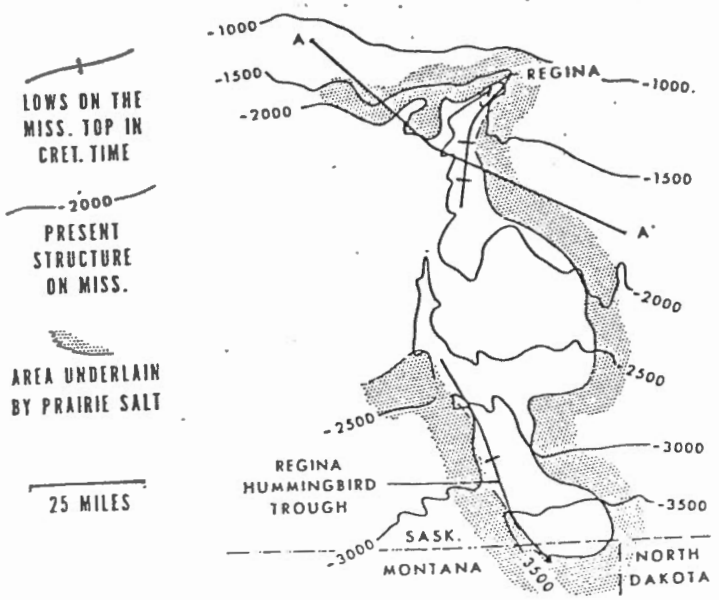

Figure 7. Mississippian structure map of Regina–Hummingbird trough. The present structural trough is the result of salt solution which began in pre-Cretaceous time throughout the trend and recurred in post-Cretaceous time at the north end. *See* Figure 8 for structure along A–A'.

Fig. 5. (DeMille et al. 1964)

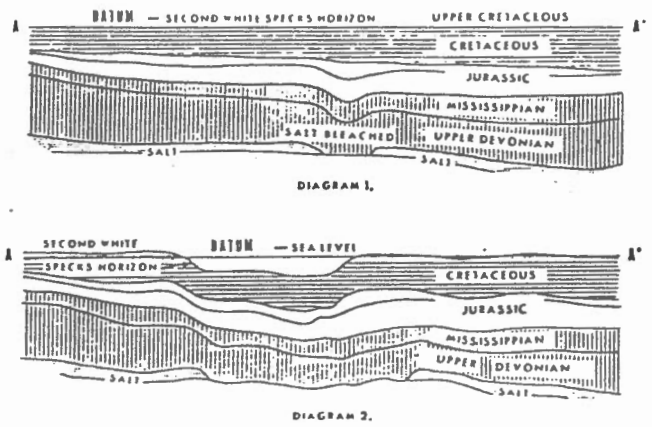

Figure 8. Structural section Regina-Hummingbird trough. The structure along Section A–A' (Fig. 7) is illustrated schematically in diagram 1 for the Late Cretaceous time; diagram 2 shows the present-day, much broader area of salt removal. Length of section 40 miles, thickness 3500 feet.

Fig. 6. (DeMille et al. 1964)

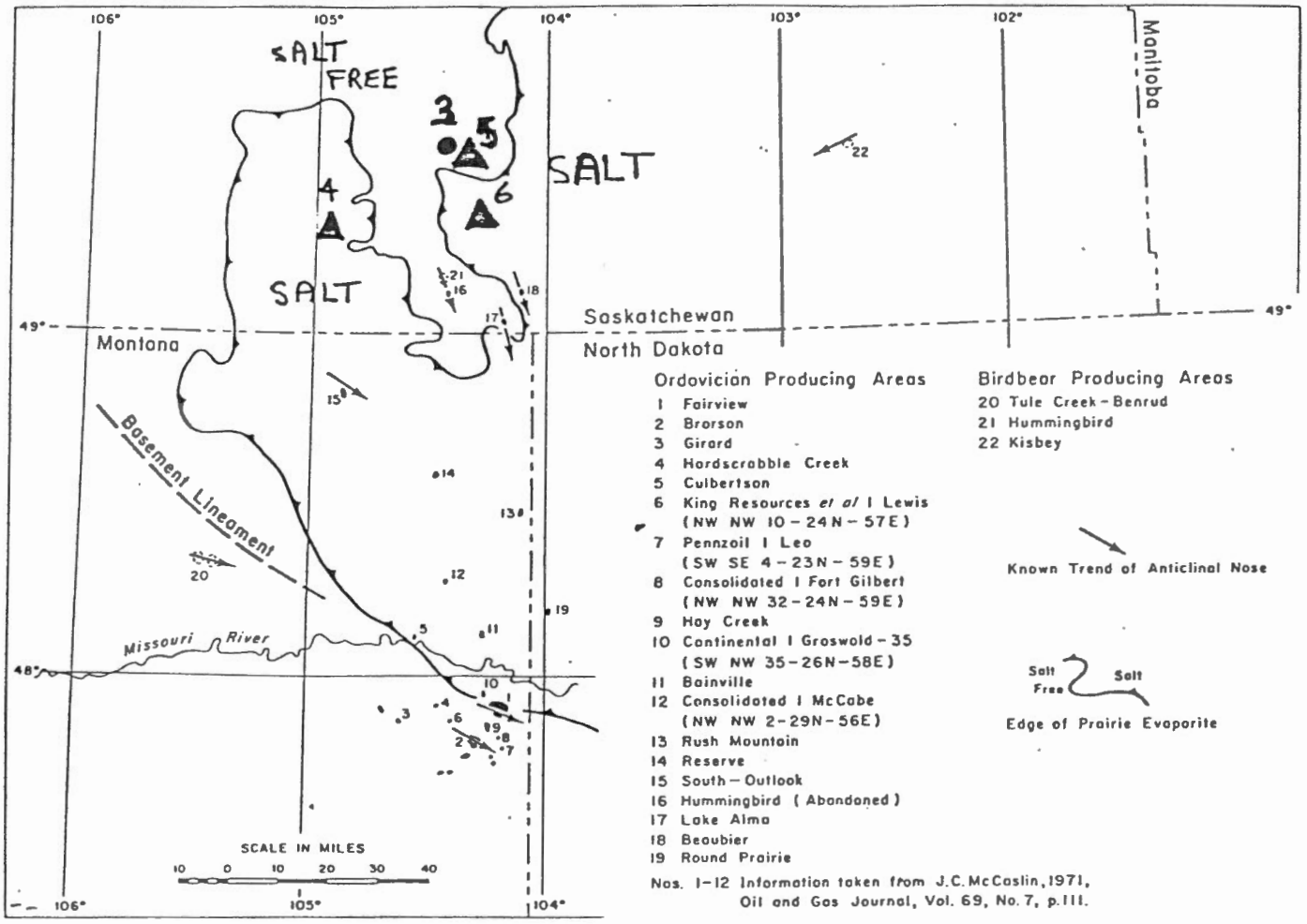

Fig. 23. Map showing distribution of Upper Ordovician and Upper Devonian oil fields in northeastern Montana and southeastern Saskatchewan (D. M. Kent).

Fig. 7. (Christopher et al. 1971)

CONCLUSIONS

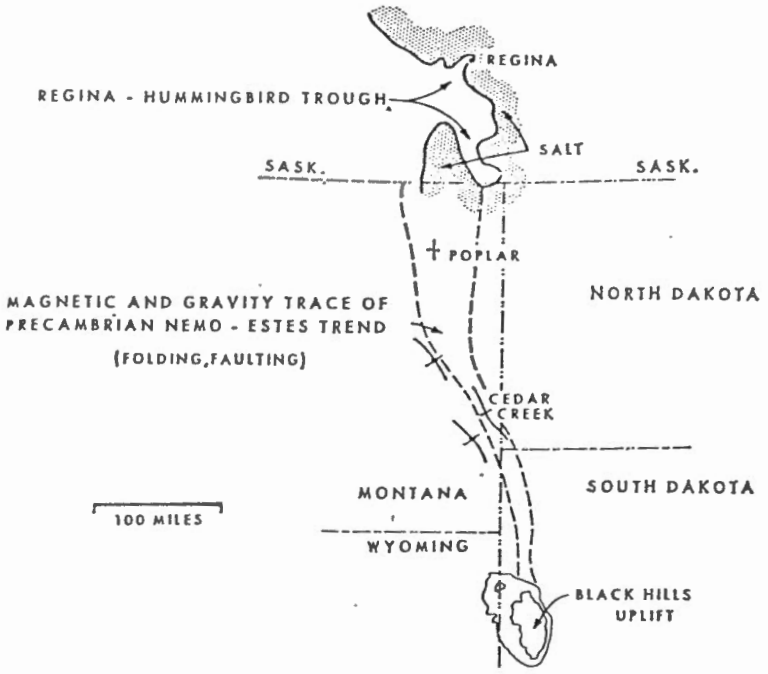

Figure 9. Tectonic sketch, Nemo-Estes trend, showing the coincidence of the Regina-Hummingbird trough and the Nemo-Estes tectonic trend which suggests a relationship between these features.

Fig. 8. (De Mille et al. 1964)

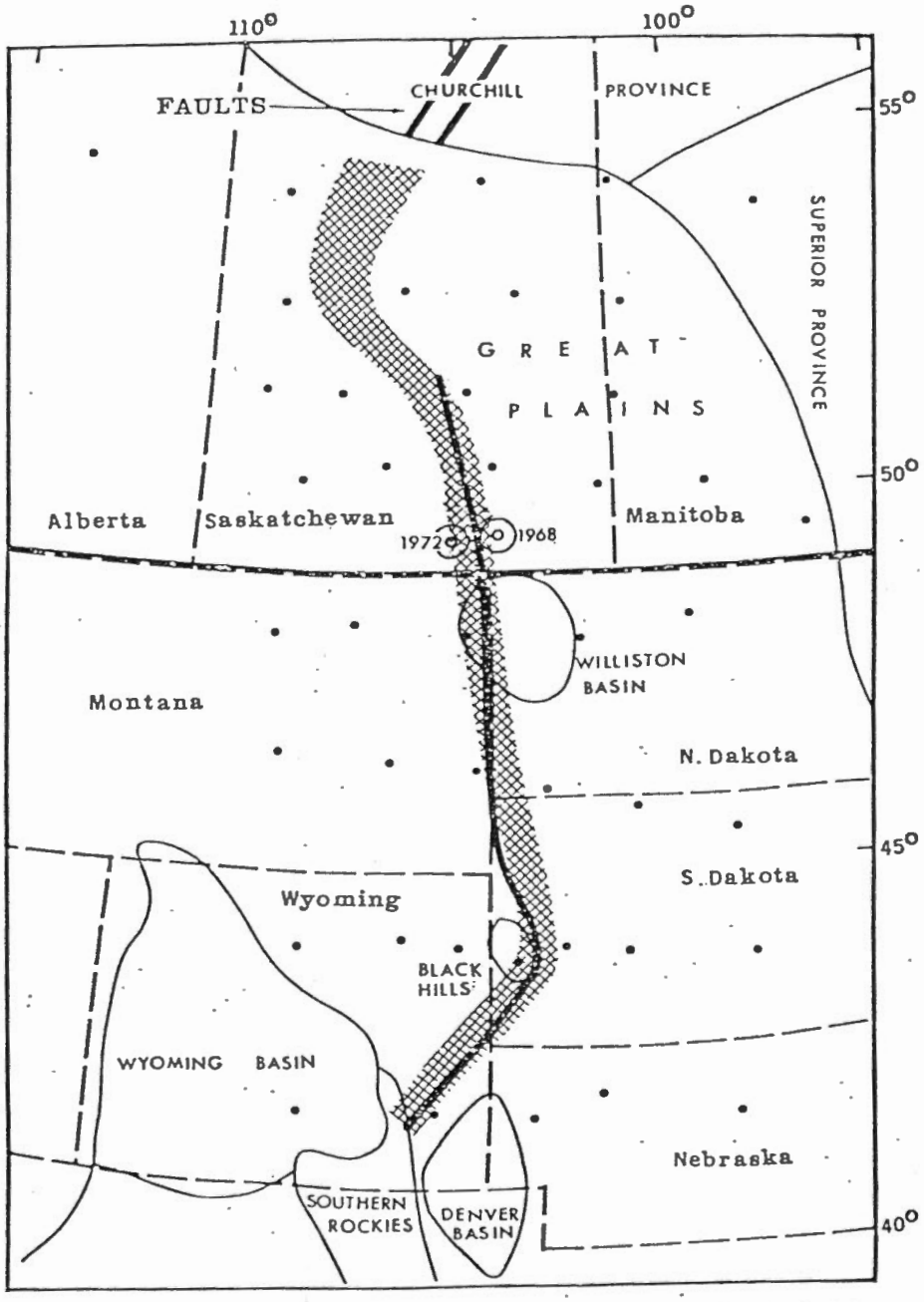

FIG. 3. Location of the North American Central Plains conductive body. The broad shaded strip represents information from magnetograms of 'world-wide' events and from quadrature-phase induction arrows. The black line locates the axis of the conductor more accurately from Fourier coefficient maps discussed in the text. In the Churchill Province Shield, the Wollaston Lake Fold Belt lies northwest of the faults, and the La Ronge–Reindeer Lake Belt, southeast. The double circles mark earthquake epicentres, and the dots show magnetometers.

Fig. 9. (alabi et al. 1975)