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REGIONAL DISTRIBUTION AND °API GRAVITY OF OIL INCLUSIONS FROM UPPER ORDOVICIAN YEOMAN FORMATION, SOUTHEAST SASKATCHEWAN: EVALUATION OF POTENTIAL HYDROCARBON MIGRATION PATHWAYS

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SUMMARY

Fluorescence microscopy of polished potential source rocks, carrier beds and potential reservoir facies has defined three Types of crude oil inclusions in Upper Ordovician Yeoman Formation of southeastern Saskatchewan. Type C appear to be the earliest, are heavy (~ 15 to < 20 °API), and are most likely to be locally sourced. Type B and A oil inclusions represent crude oils which migrated through the Yeoman Formation after Type C oils. Types B and A oil inclusions are of intermediate (25 and < 35° API) and high gravity (>35 to <50 °API), respectively. Regionally in the study area, the main focus of crude oil migration in the Yeoman Formation, as represented by Type A and B oil inclusions, coincides with regions of elevated thermal maturity.

INTRODUCTION

This Open File Report reports on data which evaluates the °API gravity and distribution of microscopic crude oil and hydrocarbon fluid inclusions (hereafter referred to collectively as oil inclusions) in Upper Ordovician Yeoman Formation of southeastern Saskatchewan (Fig. 1) using fluorescence microscopy and microspectrometry. Spectral fluorescence parameters for the oil inclusions are used to evaluate oil gravity relative to the timing of their emplacement in potential hydrocarbon source rocks, carrier beds and reservoir rocks. Regional mapping of the fluorescence parameters demonstrates where crude oils most likely migrated in the Yeoman petroleum system.

For references pertaining to details of geology, petroleum geology, hydrocarbon source rock evaluation, oil-source correlation, migration, thermal maturity, organic petrology and hydrocarbon generation modeling for Ordovician strata in southeastern Saskatchewan refer to Osadetz et al., (1989), Campbell and Forbes (1990), Stasiuk and Osadetz (1990, 1993), Stasiuk et al., (1994), Osadetz et al., (1992), Fowler, (1992), Osadetz and Snowdon, (1995), Buruss et al., (1996), Haidl et al., (1996), Li et al., (1998), and Fowler et al., (1998), and references therein.

Figure 1. Study area in southeastern Saskatchewan (from Osadetz et al., 1992).

Crude oil inclusions in rocks: General

Crude oils are present in a variety of geological environments and can occur as economic accumulations in reservoir rocks, or as hydrocarbon fluid inclusions trapped within diagenetic minerals, or as isolated, microscopic oil globules trapped in inter- and intracrystalline porosity (e.g. Burruss, 1981; McLimans, 1987; Guilhaumou et al., 1990; Stasiuk and Snowdon, 1997). Hydrocarbon fluid inclusions are generally entrapped within recrystallized minerals, overgrowths, and cements (inc. fracture-fill cements). Microscopic oil globules trapped in pore spaces or in an intracrystalline habit are sometimes associated with hcfi; in some cases oil globules are the only remaining evidence for petroleum migration through a rock.

Oil inclusions can be readily identified using fluorescence microscopy of polished rock samples because crude oils emit fluorescence in the visible light region during ultra-violet and blue light irradiation. The fluorescence properties (e.g. color, emission maxima) of oil inclusions, and crude oils, reflect their chemical composition (i.e. aromatic and saturate hydrocarbons; NSO-bearing asphaltenes and resins) as well as the density, or gravity of the oil (Fig. 2) (see Stasiuk and Snowdon, 1997, and references therein). In general, the lightest and most thermally mature oils have the shortest wavelength or 'blue region' fluorescence, and the heaviest, least mature oils have longer wavelength, 'red region' fluorescence (Fig. 2). As a result of these relationships, fluorescence studies of oil inclusions can therefore provide valuable information about local and regional scale distribution of oil types and their migration within a petroleum system (see Stasiuk et al., 1998).

METHODOLOGY

Core samples were collected from potential hydrocarbon source rocks and from stained carrier beds and potential reservoir facies of the Upper Ordovician Yeoman Formation (Table 1). Whole rock samples were crushed into 1 to 5 mm particles and/or cut into 1 to 2 cm^3 blocks, set in epoxy and polished in preparation for incident light microscopy.

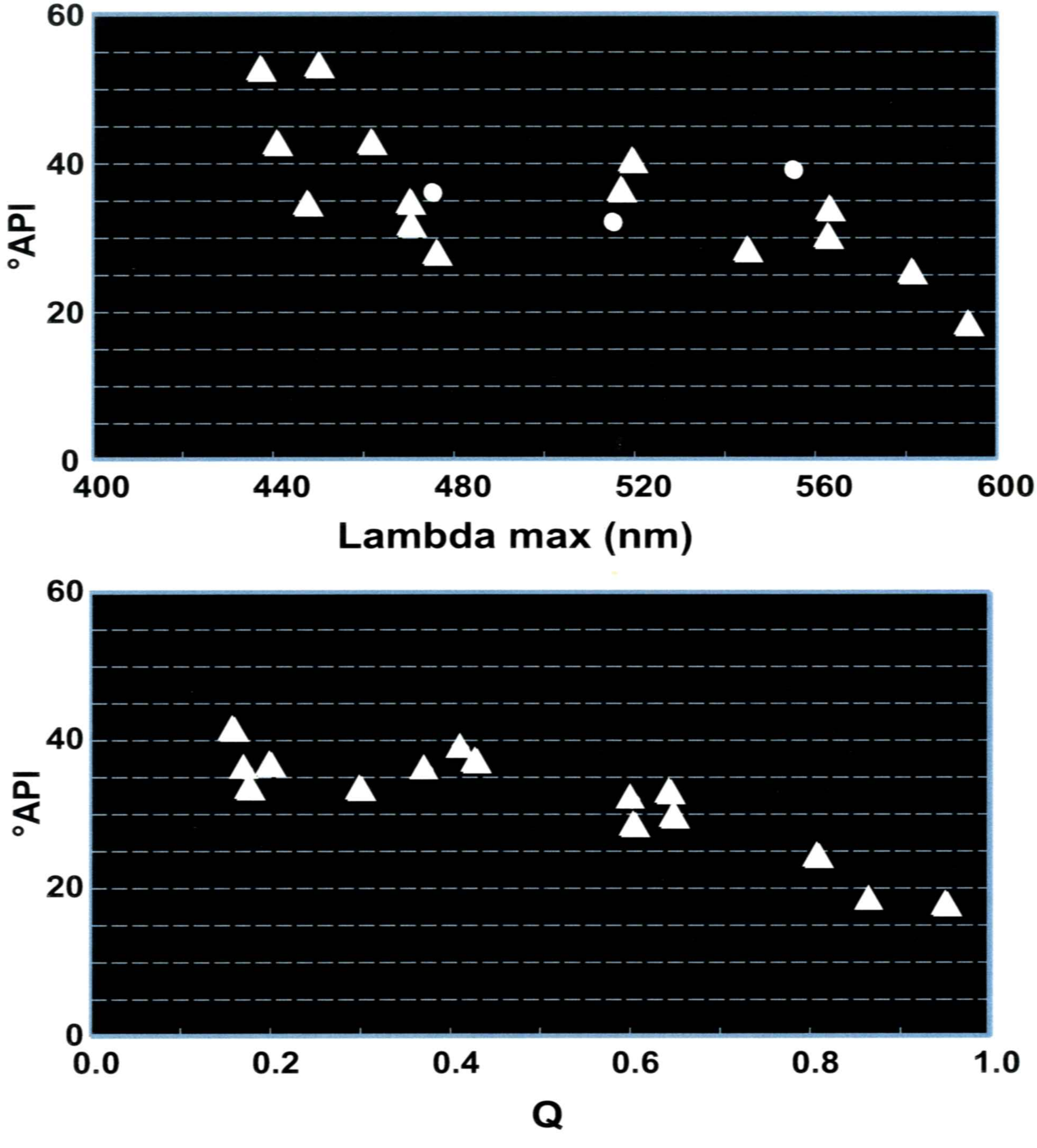

Figure 2. Relationship between gravity of crude oil (API) and fluorescence parameters, Lmax and Q (from Stasiuk and Snowdon, 1997).

Fluorescence intensity measurements (400-700 nm) were made on the oil inclusions using a Zeiss MPM II Universal incident light microscope (HBO 100 ultraviolet source), a Zeiss 03 photomultiplier, a Zeiss Continuous Filter Monochromator b (1/2 band width of 14 nm at 540 nm) and a Zeiss Axiophot II microscope-photometer-monochromator system. Epiplan-neofluor oil (Cargille Type FF immersion oil, n= 1.4810) and water immersion objectives (x40 objectives for total magnification of 640 x) were used for analysis. A Zeiss Ultraviolet G 365 nm excitation filter (395 nm beam splitter; 420 nm barrier filter) was used for sample illumination. Zeiss Lambda Scan software was used to record, correct (i.e. black body correction) and average spectra. The monochromator was standardized against three fluorescing plexiglass standards (Lmax = 504 nm, 580nm and 604 nm).

Between 5 and 15 spectra were measured for the paragenetically discriminated oil inclusions; these spectra were then averaged. Oil inclusions with the shortest wavelength fluorescence (i.e. nearest the blue region) within any given 'paragenetic mineral phase' or within a population of intra- and intercrystalline oil globules, were selected for analysis. Two spectral parameters have been used to characterize the fluorescence properties of the oil inclusions: (i) Lambda max (**Lmax** = wavelength of maximum emission intensity in nm) and; (ii) a red/green quotient (**Q** = $Intensity_{650nm}/Intensity_{500nm}$). Fluorescence alteration of well sealed hcfi and entrapped oil globules was generally not problem; when extensive fading occurred or the inclusions ruptured during analysis the spectrum were not used.

The relationship between the Lmax, Q and °API, is shown in Figure 2 (see also Stasiuk and Snowdon, 1997 where Lmax and Q values of crude oils are also correlated with percent saturates, aromatics, resins and asphaltenes). These cross plots form the basis for estimating the gravity of the oil inclusions. Lmax values have also been plotted and contoured for each of the three oil types defined for the Yeoman Formation to express regional distribution of the oil inclusions and potential hydrocarbon migration pathways.

RESULTS AND DISCUSSION

Oil globule and hydrocarbon fluid inclusions

Table 1 presents the well locations, sample depths, and Lmax and Q fluorescence data for the oil inclusions evaluated from the Yeoman Formation in southeastern Saskatchewan. Based on paragenetic occurrence of the inclusions and Lmax and Q values, three populations of oil inclusions can be defined within the Yeoman Formation:

(i) Type C oil inclusions are paragenetically the earliest oils and have Lmax values ranging from 580 to 610 nm and Q values ranging from 0.8 to 1.4. Type C oil inclusions represent heavy crude oils with an estimated gravity between 15 and < 20 °API. The distribution of these oils, in terms of Lmax is presented in figure 3. These oil inclusions are interpreted to be derived from thermal maturation of Type II kerogen source rocks in southeastern Saskatchewan, thus representing local hydrocarbon generation (see also Fowler et al., 1998; Li et al., 1998). The source of these heavy oils is interpreted to be 'diluted' or non-kukersite hydrocarbon source rock intervals which are characterized by relatively low total organic carbon, relatively low hydrogen indices, and organic microfacies consisting of small, disseminated *G. prisca* alginites, acritarchs, unicellular Prasinophyte alginites and amorphous organic matter (see Fowler et al., 1998).

(ii) Type B oil inclusions are paragenetically younger than Type C oil inclusions and have Lmax values ranging from 505 to 545 and Q values ranging from 0.28 to 0.67. As hcfi, these oil inclusions mainly occur in late stage dolomite and calcite overgrowths and cements, as well as in micro-fractures. Type B oil inclusions are of intermediate oil gravity with an estimated API of between 25 and < 35°. The distribution of these oils, in terms of Lmax is presented in figure 4. The Type B oils are interpreted to represent oils which have migrated into the reservoirs from a distance and are therefore most likely not locally sourced (see also Fowler et al., 1998; Li et al., 1998).

(iii) Type A oils inclusions are also paragenetically younger than Type C oil inclusions, and appear to have migrated through the Yeoman Formation at about the same time as Type B oil inclusions, or in some locations just after.

Table 1. Locations, depths and fluorescence data for oil globule, and hydrocarbon fluid inclusions in the Upper Ordovician Yeoman Formation, southeastern Saskatchewan

Location	Depth (m)	GSC C#	GSC	Lambda Max (nm	R/G Q	Oil type
5-31-13-32W1	1683.25	-	-	-	-	-
5-31-13-32W1	1685.00	-	-	-	-	-
3-8-1-11W2	3186.50	405222	446-99	460	0.10	A
3-8-1-11W2	3186.50	405222	446-99	520	0.35	B
11-19-1-12W2	3156.50	-	-	465	0.23	A
10-25-1-15W2	3144.00	405237	462-99	460	0.18	A
10-25-1-15W2	3144.00	405237	462-99	505	0.41	B
10-25-1-15W2	3144.00	405237	462-99	610	1.55	C
1-14-1-17W2	3094.60	405208	432-99	435	0.20	A
1-14-1-17W2	3094.60	405208	432-99	580	0.90	C
1-14-1-17W2	3101.00	405209	433-99	460	0.30	A
1-14-1-17W2	3101.00	405209	433-99	530	0.50	B
1-14-1-17W2	3101.00	405209	433-99	590	0.70	C
1-14-1-17W2	3107.40	405210	434-99	450	0.40	A
13-23-1-17W2	3074.50	405251	476-99	450	0.30	A
11-27-1-17W2	3072.20	405257	482-99	445	0.30	A
16-36-1-18W2	3062.00	405262	487-99	460	0.30	A
16-36-1-18W2	3062.00	405262	487-99	515	0.51	B
15-9-2-14W2	3029.70	405225	449-99	580	0.60	C
8-16-2-14W2	3053.00	405234	458-99	450	0.20	A
8-16-2-14W2	3053.00	405234	458-99	590	1.40	C
3-20-2-16W2	3071.20	405238	463-99	440	0.30	A
3-20-2-16W2	3071.20	405238	463-99	530	0.61	B
6-13-2-19W2	3020.30	405265	490-99	600	1.20	C
12-13-2-19W2	3018.50	405267	492-99	460	0.40	A
12-13-2-19W2	3018.50	405267	492-99	590	0.90	C
11-14-2-19W2	2979.70	-	-	500	0.30	B
2-8-3-14W2	2929.50	-	460-99	460	0.30	A
7-23-3-17W2	2990.20	405260	485-99	440	0.1	A
7-23-3-17W2	2990.20	405260	485-99	510	0.35	B
11-2-3-21W2	2864.40	405272	497-99	520	0.45	B
11-2-3-21W2	2871.40	405273	498-99	-	-	-
7-28-4-4W2	2583.3	-	-	-	-	-
3-26-4-20W2	2820.20	405268	493-99	545	0.49	B
3-26-4-20W2	2821.40	405269	494-99	460	0.15	A
3-26-4-20W2	2821.40	405269	494-99	515	0.35	B
3-26-4-20W2	2822.90	-	-	-	-	-
10-18-5-20W2	2771.20	-	70-99	505	0.28	B
10-18-5-20W2	2771.20		70-99	590	1.07	C
10-18-5-20W2	2774.50	-	71-99	430	0.17	A
9-28-6-11W2	2610.60	-	-	580	0.90	C
9-28-6-11W2	2610.85	-	-	510	0.52	B
9-28-6-11W2	2610.85	-	-	455	0.15	A
8-2-6-16W2	2685.50	405240	465-99	500	0.30	B
8-2-6-16W2	2685.50	405241	465-99	585	1.00	C
5-8-6-19W2	2709.50	-	76-99	435	0.10	A
5-8-6-19W2	2709.50	-	76-99	540	0.67	B
5-8-6-19W2	2709.50	-	76-99	585	1.40	C
15-4-7-10W2	2569.40	check	check	460	0.15	A
15-4-7-10W2	2559.00	check	check	520	0.50	B
16-20-8-10W2	2445.50	405221	445-99	520	0.50	B
6-32-8-16W2	2458.80	405241	466-99	585	1.00	C
3-14-8-20W2	2577.08	405270	495-99	510	0.50	B
3-14-8-20W2	2577.08	405270	495-99	585	1.03	C
16-8-9-21W2	2526.8	-	-	525	0.55	B
16-8-9-21W2	2526.8	-	-	580	0.80	C
16-8-9-21W2	2558.80	-	-	520	0.45	B
6-27-14-2W2	1761.16	-	-	-	-	-
6-27-14-2W2	1765.20	-	-	-	-	-
6-27-14-2W2	1767.48	-	-	-	-	-
6-27-14-2W2	1771.44	-	-	-	-	-
6-27-14-2W2	1772.81	-	-	-	-	-
14-11-14-16W2	2125.70	405243	468-99	-	-	-
14-11-14-16W2	2136.00	405242	467-99	-	-	-
1-25-23-16W2	1599.30	405244	469-99	-	-	-
1-25-23-16W2	1692.30	405245	470-99	-	-	-
NW36-51-8W2	1756.84	-	-	-	-	-
4-10-33-1W3	1466.40	405214	438-99	-	-	-
4-10-33-1W3	1466.70	-	-	-	-	-

As for Type B oil inclusions, Type A hcfi also occur mainly within late stage dolomite and calcite overgrowths and cements as well as in micro-fractures. Type A oil inclusions have Lmax values ranging from 435 to 460 nm and Q values ranging from 0.10 to 0.40 indicating they are of intermediate to high gravity with an estimated API of > 35 to < 50°. The geographic distribution of these oils, mapped in terms of Lmax is presented in figure 5. The Type A oil inclusions represent the most thermally mature crude oils and thus the most distally migrated hydrocarbons in the Yeoman petroleum system of southeastern Saskatchewan (see also Fowler et al., 1998; Li et al., 1998).

Comparison of crude oil inclusion distribution and thermal maturity

A clear relationship exists between the regional distribution of Type A, B and to a lesser degree between Type C oil inclusions (Figs. 3-5) and regional iso-thermal maturity contours of Yeoman Formation potential hydrocarbon source rocks (Fig. 6-8). Thermal maturity in the Yeoman Formation is best expressed as per cent reflectance in oil (%Ro) of: *G. prisca* disseminated alginite (Fig. 6), *G. prisca* mat alginite (Fig. 7) and, bitumen and pyrobitumen (Fig. 8), with regions of highest thermal maturity represented by the highest %Ro values in the maps[1].

The main focus for migration of high gravity Type A and intermediate gravity Type B oil inclusions (centered about Ranges 17-20W2, and Townships 8-15W2; Figs. 4 and 5) corresponds to areas within, and north of regions which have the highest levels of thermal maturity in the Yeoman Formation (centered about Ranges 17-20W2, and Townships 8-15W2) (Figs. 7-9).

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[1] for details on thermal maturity evaluation using (i.e. organic-walled, algal-derived, dispersed organic matter) %Ro and fluorescence parameters of alginite macerals see Stasiuk and Osadetz (19930 and Stasiuk et al., (1994).

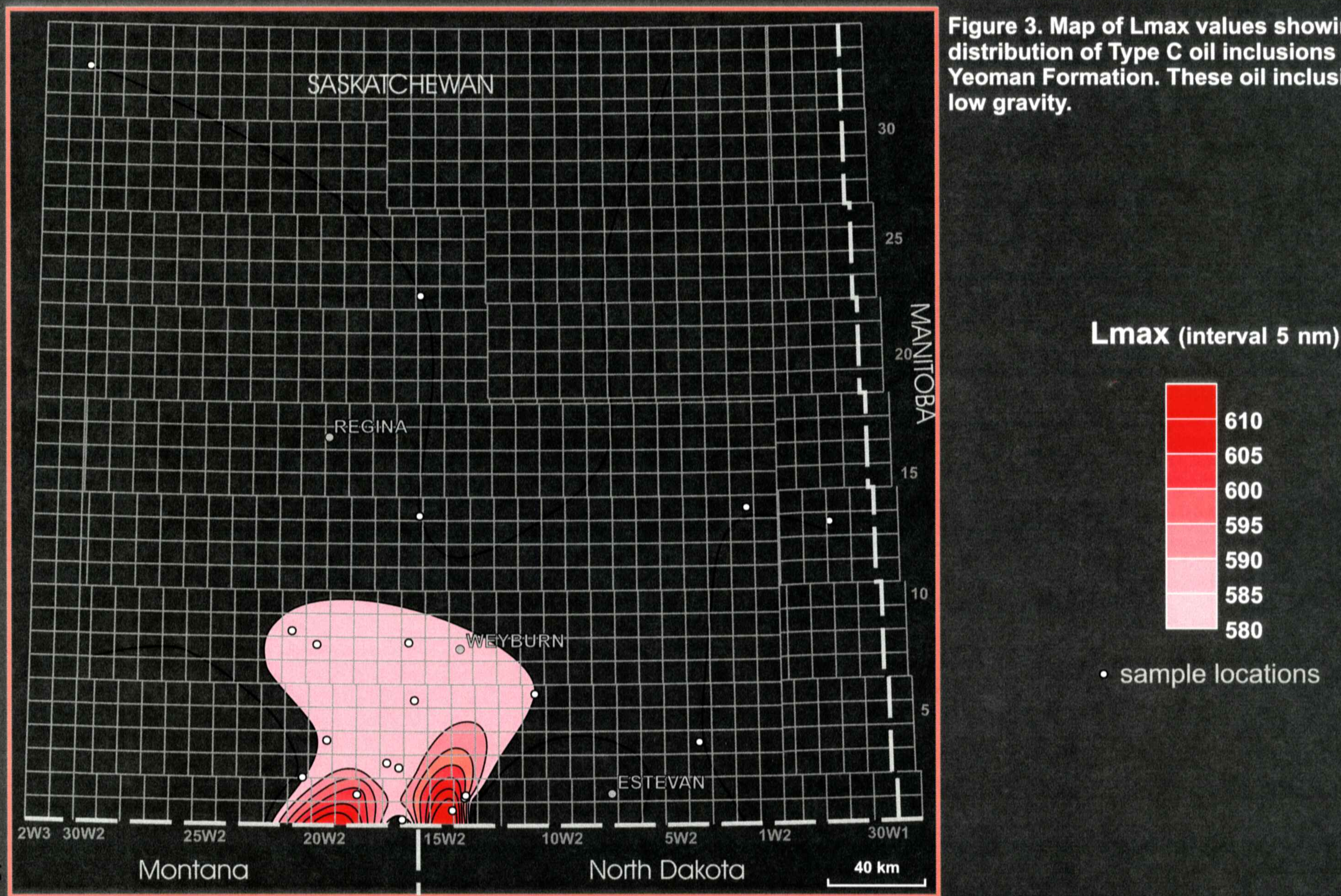

Figure 3. Map of Lmax values showing the distribution of Type C oil inclusions in the Yeoman Formation. These oil inclusions are low gravity.

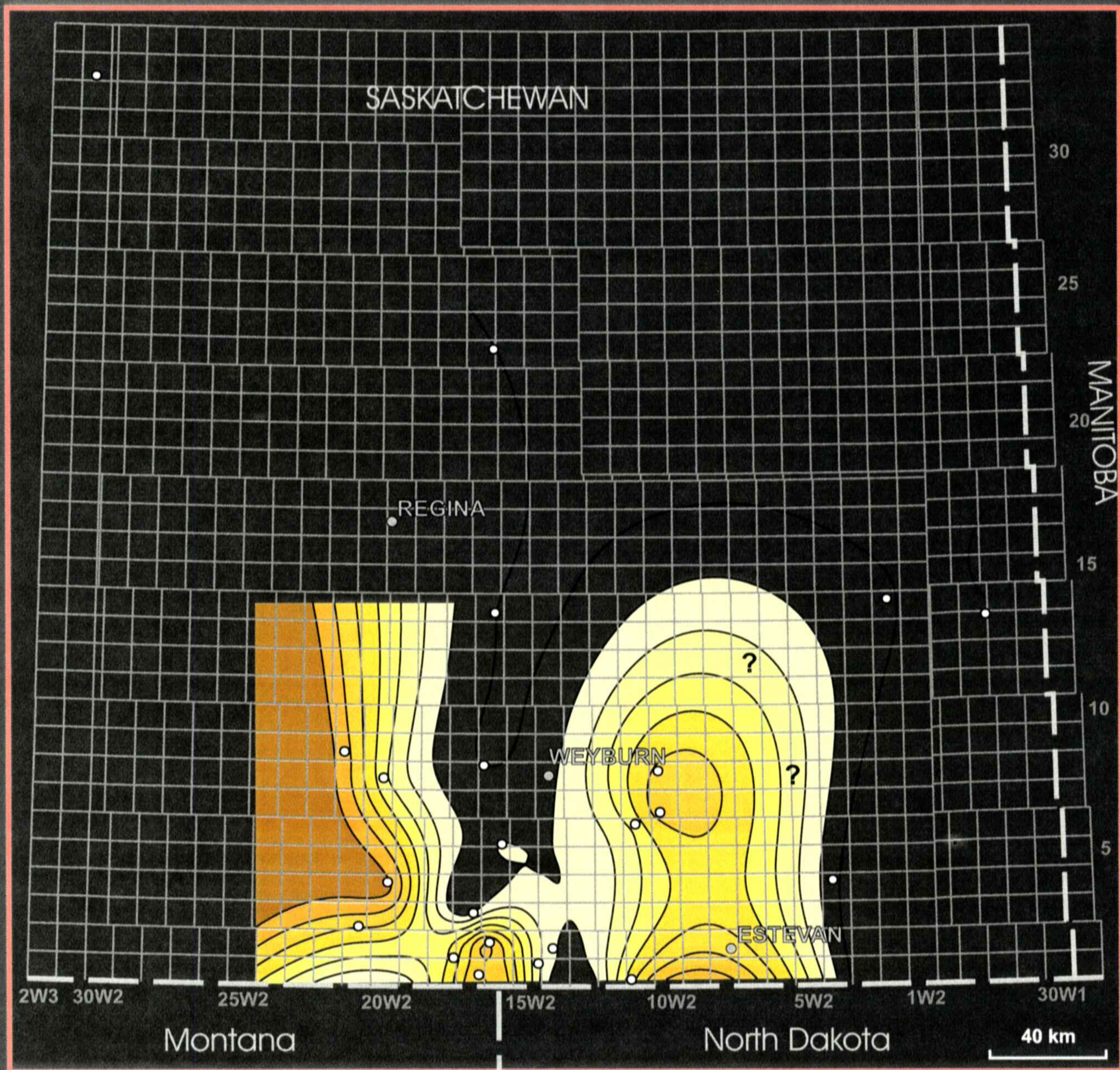

Figure 4. Map of Lmax values showing the distribution of Type B oil inclusions in the Yeoman Formation. These inclusions are of intermediate gravity.

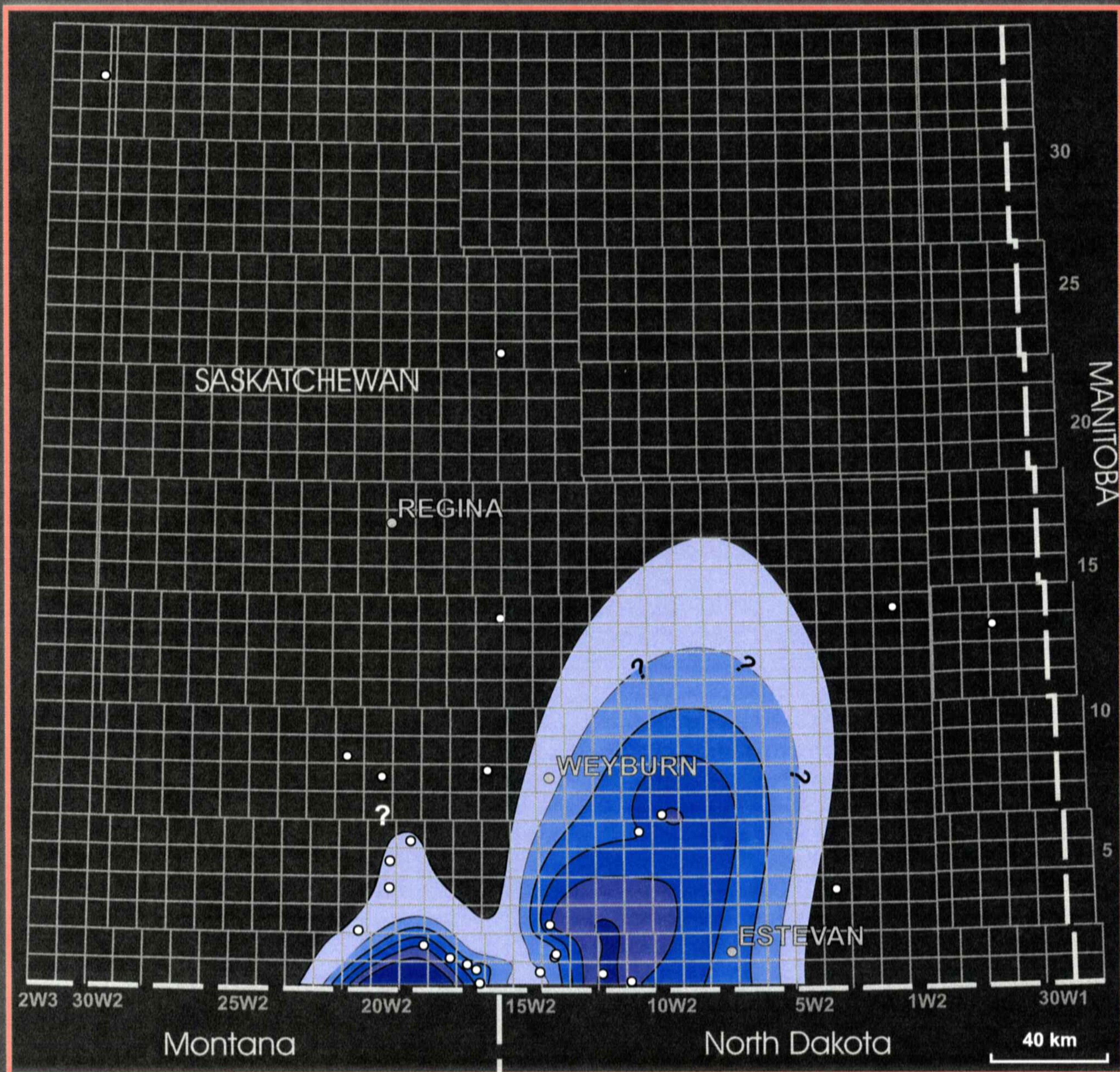

Figure 5. Map of Lmax values showing the distribution of Type A oil inclusions in the Yeoman Formation. These inclusions are of high gravity.

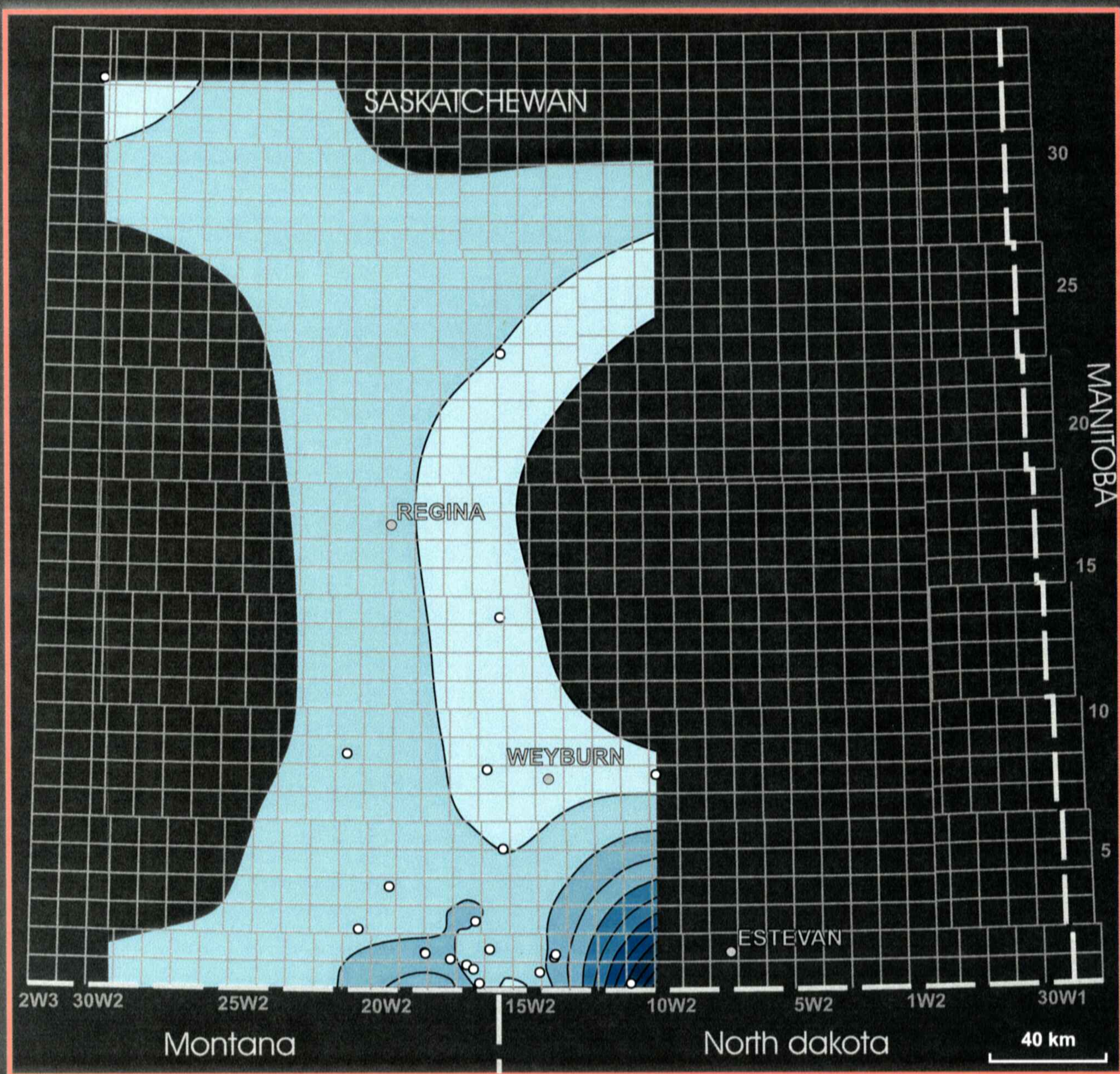

Figure 6. Iso-reflectance (%RoRandom) map for disseminated *G. prisca* alginite in the Yeoman Formation.

%R_o Random (contour interval 0.05)

0.50
0.40
0.30
0.20
0.10
0.05

• sample locations

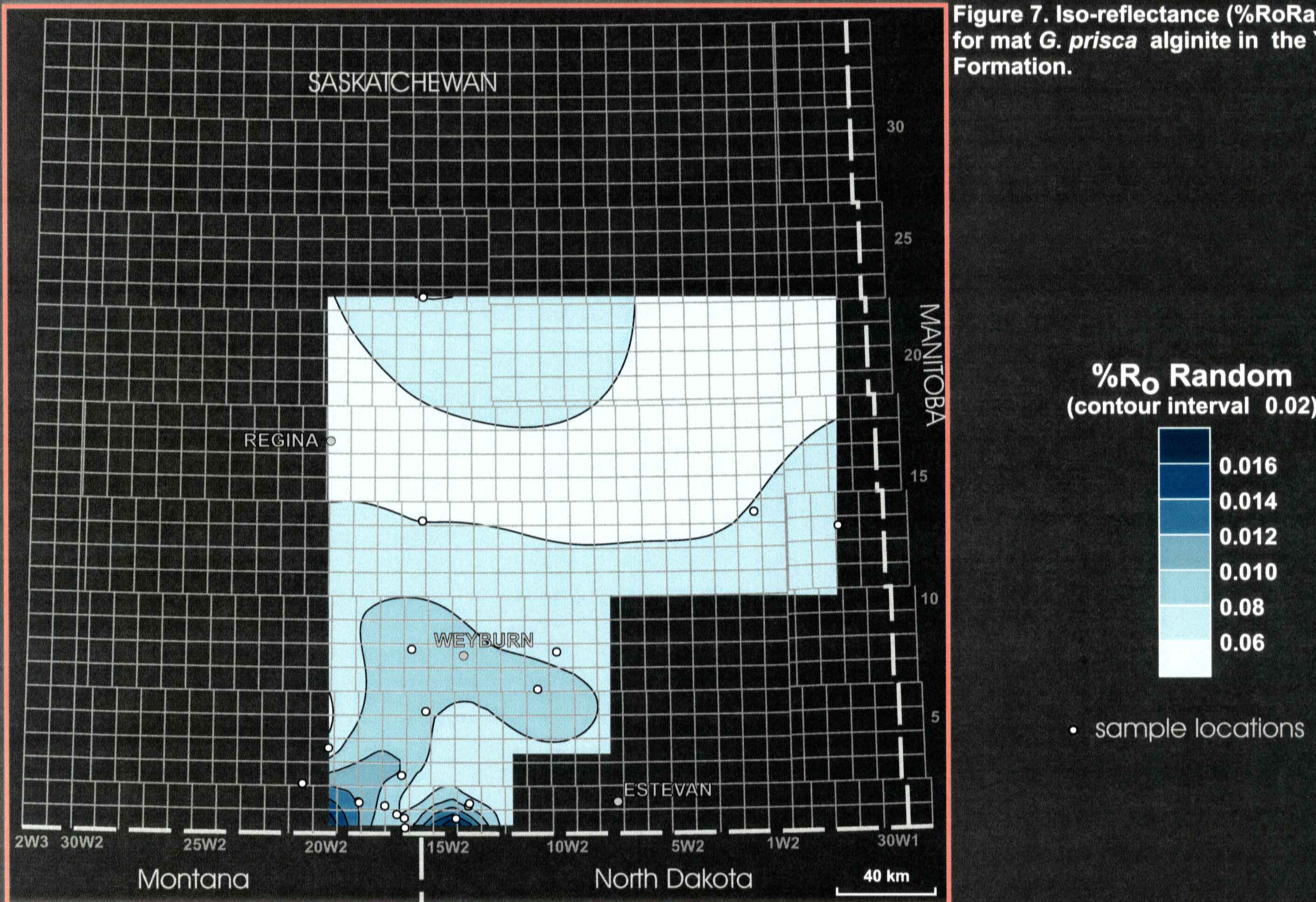

Figure 7. Iso-reflectance (%RoRandom) map for mat *G. prisca* alginite in the Yeoman Formation.

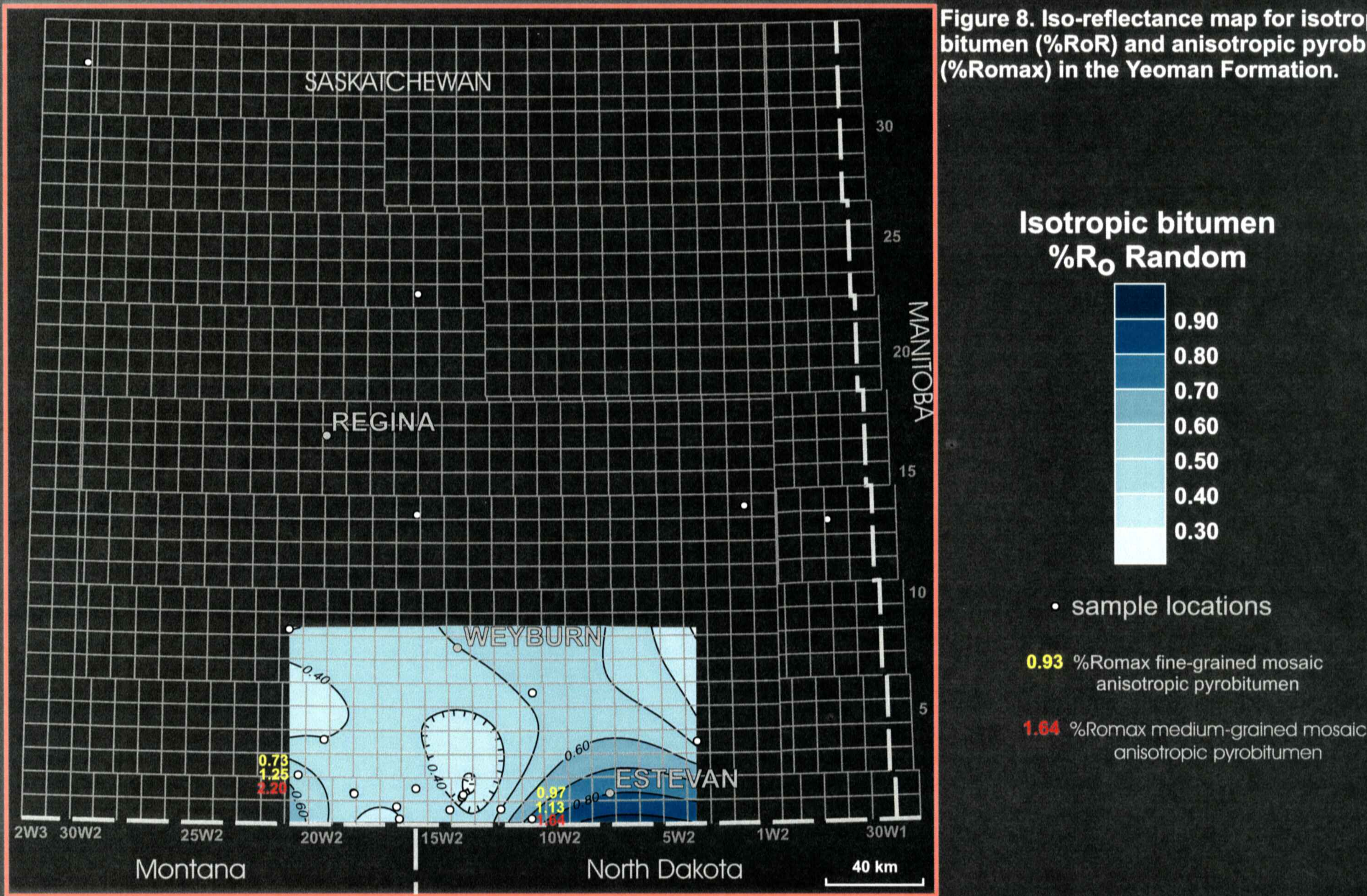

Figure 8. Iso-reflectance map for isotropic bitumen (%RoR) and anisotropic pyrobitume (%Romax) in the Yeoman Formation.

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